PRODUCT ENGINEERING

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What Material?

PRODUCT ENGINEERS are active today in such widely different fields that more and more of their problems tend to be specialized. But there is one fundamental consideration that is common to all fields, and will continue to be so long as engineers design things to be made out of the materials available to mankind. That consideration is the selection of the right material for the job at hand.

THIS number of *Product Engineering* is devoted to a discussion of material selection. Obviously, no editor in his senses would expect to include within the covers of one issue of a magazine a comprehensive treatment of all engineering materials. To make the issue a practical possibility the list of materials to be considered was limited to the ferrous and non-ferrous metals and alloys, and the requirements to be met were confined to what we think of as the more exacting ones. These are: corrosion, erosion and abrasion resistance; impact and fatigue strength; high strength-weight ratio and lightness; strength at high temperatures.

IN VIEW of the vast array of alloys and metals, even in the limited group we chose for consideration, no one man could expect to have a comprehensive knowledge of all of them and their applications. The only answer was to go to the readers of *Product Engineering* and to collect from them their experiences in dealing with our list of requirements and the group of materials we had selected.

ONE MEMBER of the staff has spent all of his time for over two months on the task of interviewing engineers, gathering their experiences and sorting them out into a logical and connected story of material selection. Other members of the staff have devoted what time they could spare from other work.

WE WISH to express to the more than three score engineers who contributed to this number of *Product Engineering* our grateful appreciation of their help in making this article a comprehensive survey of the materials in use.

OUR ONLY regret is that practical limitations made it impossible, within the time available, to visit more of the readers of *Product Engineering* and exchange experiences. To a professional man there is nothing more fascinating than to hear how a colleague mastered a professional problem. Golf, cards, the flowing bowl—now that it can be mentioned freely once more—all are conducive to good-fellowship, but the interchange of ideas with a brother member of the profession leads to greater mutual respect and a more enduring relationship.

WE TRUST that this number of *Product Engineering*, contributed by readers and coordinated by the staff, may be a medium for that interchange of ideas that is so valuable. Since interchange involves action by both parties we hope that the opinions expressed and experiences quoted will generate discussion from other readers.

Materials That Meet The Requirements

Summarizing opinions and experiences of more than seventy engineers in the selection of ferrous and non-ferrous metals and alloys for resistance to corrosion, erosion, wear, fatigue, impact, creep, high temperatures and for weight saving

Introduction

BECAUSE of the many factors that are involved, it is impossible to state hard and fast rules for the selection of a material for any given application. In every instance there are physical and chemical requirements of varying degrees of relative importance. Properties of the material that affect the manufacturing processes must be considered. And finally there is the question of cost versus commercial value. Rules, formulas and laboratory tests cannot answer this last question. It is one that can be decided only by an engineering sense of values and commercial intuitions.

Even the significance of a given service requirement is entirely different in the various fields of product design. Corrosion in chemical equipment usually implies destruction of the material, whereas in dairy and food equipment corrosive effects are measured by the contamination of the food products that are handled. Non-rusting shafts are used on impeller-type pumps to avoid wear and tear on the pump packings by a pitted shaft. As a further example, corrosion-resisting materials are used in airplane construction in order to make it unnecessary to provide additional thicknesses to compensate for corrosion.

Even if costs and those material properties that affect the manufacturing processes be not taken into consideration, there are usually several overlapping requirements that must be met. Materials for turbine blading are a striking example wherein a great number of factors are involved. The material used must have high strength, permanence over long periods of time, and must resist fatigue, corrosion and erosion. Although this material application presents an unusual situation, it will be found that in most instances there are at least two distinct requirements of almost equal importance that must be met.

As a further complication in the selection of materials, there are always commercial reasons that govern. Service value as measured by a customer involves many elements. The trade being served may have standards of acceptance, some of which have been more or less arbitrarily established by custom and experience. In some instances, the materials must conform to the legal requirements established by Boards of Health, state legislatures or governmental bureaus such as the Bureau of Explosives.

In at least one field of design, the unusual conditions under which the product is used limits the selection of materials. On account of interchange, freight cars purchased by one railroad frequently are found in use on competing or other roads. The railroad company purchasing the freight car is therefore not willing to pay for a car built of alloy steels or other high-grade materials. Any operating economies resulting from the lighter or improved car would go into the pocket of the railroad that is using the equipment rather than the railroad that originally purchased it. This is strikingly emphasized by the fact that passenger cars which are not interchanged among the various roads have been improved with anti-friction bearings and higher grade materials, this also holding true for locomotives.

IN many products, particularly mechanical equipment for the home, style is of importance. A prospect will be more inclined to buy "the kind of machine Mrs. Jones has" rather than a unique piece of equipment that is actually of higher quality. Many products of this group have failed to "go across" simply because their design was ahead of the times.

Cost cannot be based merely upon the cost per pound of material. In every instance it is the total cost of the finished product that determines which material is less expensive. Free-cutting brass or bronze is often less expensive than plain carbon steel. Money can often be saved by using die-castings in preference to gray

iron castings. If corrosion-resisting steel is used, the sheets can often be thinner than if plain carbon steel were used. Finally, the use of a more expensive material for a given part may make possible economies in the design of associated parts.

FROM the above it is evident that in a brief summary it would be impossible to consider every item that might enter into the selection of a given material for a given service. The data and information given here were contributed by a great number of designing engineers. Only the salient facts presented by them are included. Unusual conditions that had to be met are set forth in detail, whereas self-evident facts have been largely omitted.

It would, of course, be impossible to make a complete survey of all of the metals and alloys that find their way into the great variety of products that are being manufactured today. The metals mentioned in this summary comprise those finding most universal application. In a few instances, trade names are given. Wherever the information was available, the exact chemical composition is specified. On account of space limitations it was not possible to set forth in detail the heat-treatment to which the alloys were subjected. This would have been impractical on account of the wide range in heat-treatments to conform to the differences in thicknesses, as well as slight variations in the chemical composition of the metal.

In forthcoming numbers of *Product Engineering* there will be articles that will deal with the different families of alloys, setting forth heat-treatments and ranges in physical characteristics in detail and information concerning the workability of the metal.

In every problem concerning the adoption of a material there are one or more dominating service requirements such as corrosion resistance, impact strength, fatigue strength, lightness or high strength-weight ratio, resistance to abrasion, wear or erosion, strength at high temperatures, or resistance to creep. Materials applications as set forth in this article have been classified in so far as possible according to these dominating service requirements. In several instances a number of requirements all of equal importance had to be met. The summary is not confined to the purely engineering aspects of the problem but also considers the commercial aspects, namely the increased sales value of the product as a result of the use of special materials. Many of the examples indicate higher material cost but more salability.

Metals Selected for Their Resistance to Corrosion

ALMOST every problem in the selection of materials involves the question of corrosion resistance. Not only is it often the first consideration but also the most complicated one. Under certain conditions every material corrodes, dissolves or disintegrates at a more or less rapid rate. Almost every metal oxidizes or deteriorates even when subjected to only the natural elements. Some of the rare metals are exceptions. Thus it is that in an engineering sense the term "corrosion-resistant" merely implies that the material designated as such will, under the given conditions, resist corrosion, dissolution or disintegration to a satisfactory degree.

What is a satisfactory degree of corrosion resistance? As a general statement, the answer to this question is that the degree of corrosion resistance is satisfactory if the purchaser or user of the product is satisfied that for his particular requirements the results obtained are the best commercially available. This further complicates the problem. It immediately implies that the material concerned must stand up in service throughout the life of the product in which it is used. The use of more expensive materials that outlast the product is poor engineering. On the other hand, in many products the life is determined solely by the durability of the corrosion-resistant material used.

The use of a corrosion-resistant material may be required for any one of the following reasons: Surface appearance, preservation of the metal, or prevention of contamination of products with which the metal comes in contact. The first two of these reasons usually apply in all instances. The third represents the most exacting requirement and is the one that dominates the selection of materials that come in contact with food products and some chemicals.

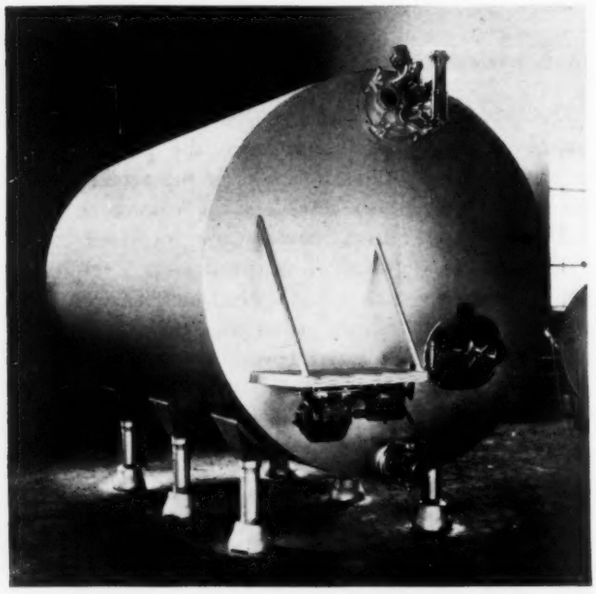
Perhaps the most exacting corrosion-resisting requirements are those found in the selection of materials for dairy equipment. Fundamentally, the problem here is to select a metal that will not only resist corrosion but also one that will not even impart a flavor to the milk or milk products. The metal must present a dense surface, must be easy to clean and must not be affected by the cleaning compound used. In addition to this, the trade using such equipment has imposed the added requirement that for milk the metal surface must have a relatively high polish, this being designated as a No. 4 polish. This approaches that of a nickel-plated surface or No. 6 polish.

Materials for Dairy Equipment

According to Loomis Burrell, vice-president in charge of new developments, and other engineers of the Cherry-Burrell Corporation, one of the leading manufacturers of equipment for handling milk and milk products, the first material used for this purpose was

tin-coated steel. The life of such equipment was relatively short because tin and iron form an electrocouple. Repeated cleaning would soon wear through the tinned surface, exposing the iron, and allowing corrosion.

To overcome this condition, copper was substituted for steel. Tinned copper proved satisfactory in many respects and is still being used to a considerable extent, particularly for pipes. Copper has several distinct advantages for certain applications. For example, its high heat conductivity together with its strength and stiffness make it particularly suitable for heat exchangers. But here again the poor wearing quality of



An all-welded 3,000-gal. milk storage tank built by the Cherry-Burrell Corporation

the tinned surface is a drawback. Repeated cleaning eventually exposes the copper. Although copper-tin is not an electrocouple, the exposed copper in contact with the milk readily produces an "off flavor."

Following the use of tinned copper for dairy equipment came the adoption of pure nickel. One of its peculiar properties is that a relatively large amount of the metal must be absorbed in the milk before any "off flavor" can be detected. As a comparison, two parts of copper in 10 million parts of milk will give a noticeable "off flavor," whereas 19 or more parts of nickel in 10 million parts of milk will not give an "off flavor" that can be detected.

Another peculiarity of nickel is that it turns a dark brown color when placed in contact with hot milk. Tests and investigations indicate that this does not harm the milk in any manner, but the discoloration of the metal is not desirable. On the other hand, there is no detectable reaction between nickel and cold milk. It appears that when the milk in the container is being heated, the metal being at a higher temperature than the milk, there is no reaction. But if the metal is cooler than the milk there is an effect, the metal apparently being slowly dissolved.

Although it had been known for quite some time that 18-8 chrome-nickel steel would be an excellent material for milk handling equipment, the adoption of this material for such purposes had to wait upon progress in welding. Today this material is welded successfully without in any way affecting its corrosion-resistant properties. Flux-coated rods of the same chemical composition, but usually with a slightly higher chromium content than the sheet, are used. With the welding operations properly supervised and provisions made to take care of the expansion of the sheet, there are no particular difficulties in the welding process. Today most of the equipment for milk and milk products is made of chrome-nickel steel.

Quoting W. J. Wachowitz, president of the Alloy Products Corporation, another leading manufacturer of dairy and food equipment, "We have built any number of pasteurizers, storage tanks, truck tanks, railroad car tanks and similar equipment out of 18-8 chrome-nickel steel. Up to this time we have not had a single failure. It is a proved fact that when this chrome-nickel steel is handled properly through the course of fabrication it will be satisfactory for such purposes. There are other materials which are likewise satisfactory, such as pure nickel, straight chrome steel, aluminum, copper and monel metal, but in each instance the field of application of each of these is limited. As a general statement, the 18-8 chrome-nickel steel has proved the most satisfactory metal for general application in the dairy, food and beverage industries."

The above conforms with the statement by Cherry-Burrell engineers: "As a generalization, it may be said that nickel, aluminum, tin and chrome-nickel steels are about equally good for milk equipment."

Materials for Pipes and Fittings

With reference to pipes, tubes, fittings and accessories, these same engineers state that some tubes of chrome-nickel steel are now being used and that there is also a trend toward the adoption of Inconel tubes, an alloy composed of 83 per cent Ni, 5 per cent Fe, and 12 per cent Cr. Pipe fittings are usually nickel-plated bronze, but an increasing percentage of nickel alloy fittings is coming into use.

Although milk is affected if kept in contact with copper over an appreciable period of time, the period of contact between the milk and the metal of the fittings is of such short duration that there is no detectable effect upon the milk when using copper-nickel alloys or copper-nickel-zinc alloys for fittings. For the same reason, it is permissible to use bronze impellers and casings for the milk pumps. To further improve such pumps, chromium plating on the bronze castings has been tried out and appears to be satisfactory for certain applications.

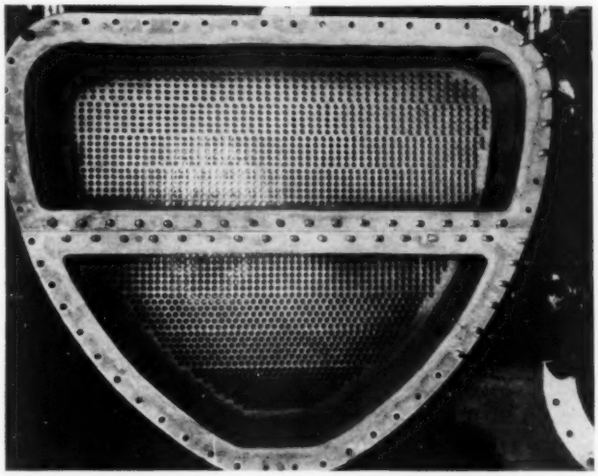
Although aluminum has not been generally accepted by the trade mainly because of the difficulty of keeping the metal polished and looking clean, there have been a number of aluminum tanks built for automobile tank transportation. Aluminum for this purpose has an advantage in the saving of weight. In Europe most of the dairy equipment is made of aluminum alloys.

With reference to the use of "stainless-clad" steel sheets, Mr. Wachowitz states, "We have also conducted a complete research and have spent considerable time in developing and fabricating equipment made of 'stain-

less-clad' steel sheets. Most of this equipment has been truck tanks for transporting milk. We have adopted this material for certain applications and so far have a number of units working out satisfactorily in service. We believe for certain applications the clad steel will answer the same purpose as the solid sheet, and of course the main reason for its use is to reduce the cost of the equipment. We believe that wherever stainless-clad steel is used in connection with tanks that are insulated, it will serve its purpose as well as the solid corrosion-resisting steel sheet."

Tanks for Transporting Foods and Chemicals

Although the above discussion pertains primarily to milk and milk equipment, the same metals find general application in machinery for handling various food products. They are not, however, the only metals that are used for food-handling equipment, much depending upon the corrosive power of the food product. Thus, L. A. Belding, of the General American Tank Car Corporation, reports that railroad tank cars for transporting cocoanut oil in bulk are carbon-steel tanks coated with aluminum on the inside put on with the metal-spraying process. In the same manner, zinc is sprayed on the inside surfaces of carbon-steel railroad car tanks for transporting corn syrup.



Material for condenser tubes must be selected with regard to corrosive qualities of the cooling water. Aluminum-brass, Ambrac and, for certain installation, some of the other non-ferrous alloys are used by Ingersoll-Rand in their surface condensers

General American Tank Car Corporation has taken the leadership in developing railroad car tanks built of special metals for the transportation of acids and commodities that would be contaminated in carbon-steel tanks. Among these are car tanks built of solid aluminum for the transportation of acetic acid, hydrogen peroxide, formaldehyde, water-white turpentine and glycerine. They have also developed tanks built of solid stainless steel, 11-14 per cent chromium, for the transportation of nitric acid, lead-lined tanks with the lead burned on the inside of a common steel tank, for the transportation of sulphuric acid, and rubber-lined tanks for the transportation of hydrochloric acid and phosphoric acid. All of these represent developments within the past five years.

Undoubtedly the most universal applications of corrosion-resistant materials are for the preservation of the metal. For resistance to water corrosion, Worthington Pump & Machinery Corporation uses Monel metal spindles and cast bronze gears for their water meters. Westinghouse uses Everdur for the tanks of electric water heaters, the same material being used for the kitchen sinks made by the Bossert Corporation. The same metal is also used for the fuel tanks of gasoline stoves manufactured by the Collman Lamp & Stove Company.

Corrosion in Steam Condensers

Condensers for steam power plants involve a number of applications of materials to resist water corrosion. According to D. W. R. Morgan, division engineer of the Westinghouse Electric & Manufacturing Company, Muntz metal, 60 per cent Cu and 40 per cent Zn is used for condenser tubes but only where there is no contamination in the water that might cause an attack upon the high zinc content of the Muntz metal. For salty or brackish water or where the water contains acid, Admiralty metal, 70 per cent Cu, approximately 1 per cent Sn with the remainder zinc, is used. For more severe corrosion conditions such as sometimes found in the process industries, nickel steels are used for condenser tubes. For cast condenser shells, ordinary cast iron is used, this material also being used for the water boxes at the ends of the condensers. One pecularity of this application is that salty or brackish water will cause an electrolytic action to occur between the cast iron and Muntz metal or Admiralty metal tubes if such are used. As a result of this electrolytic action, a protective coating is given to the tubes.

Quoting P. A. Bancel, chief engineer of the Condenser Department of the Ingersoll-Rand Company, in some recent condenser installation where the corrosive action of the cooling water is increased by the presence of sewage, condenser tubes of aluminum-brass were used instead of Admiralty metal, and the experience to date has been favorable to the aluminum-brass. Nickel tubes and tube sheets were used in a condenser which handles process water in a rayon manufacturing plant.

In most installations, Ambrac has been less subject to corrosion scale than Admiralty metal. When newly installed, the Admiralty metal usually has a somewhat better heat transfer than Ambrac. But when in use for a short time, the lower corrosion rate of Ambrac results in a slightly better conductivity than with Admiralty tubes.

Circulating pumps as made by Westinghouse have cast-iron casings and bronze impellers. Where the water is high in acid, this combination is not satisfactory. Under such conditions, manganese bronze or Monel metal is used. In salt water, a bronze with a high lead content will corrode.

Materials for Refrigeration Equipment

According to Robert S. Wheaton, development engineer of The Vilter Manufacturing Company, on inclosed-type ammonia compressors the ammonia fumes

or gas get into the crankcase. Zinc cannot be used for any of the parts that might come in contact with the ammonia gas. The piston-pin bushings are made of a copper-tin-lead alloy, and a copper-tin-antimony babbitt is used for the bearings. This does not apply to compressors using carbon dioxide for the refrigerant. Similarly, sulphur dioxide has no corrosive action on copper, copper alloys or iron, but the presence of water in the system will cause the formation of sulphurous and sulphuric acids which will attack the above-mentioned metals.

For household refrigeration units, methyl chloride is sometimes used. This refrigerant does not attack iron, copper or copper alloys even in the presence of water. For ammonia, compressors are usually made of cast iron. Ammonia does not attack iron, wrought iron, steel, copper, tin, antimony or lead. These metals are used in the building of refrigeration equipment wherein ammonia is the working medium.

For ammonia compressors, bronze wristpin bushings are apparently satisfactory if kept coated with oil, according to N. M. Small, chief engineer of the Frick Company. Bronze wristpins, however, are not good if high temperatures are involved. This company uses tin-base die-castings for the bearings of its compressors. N. M. Small also stated that with methyl chloride units or units using Freon for the refrigerant, copper or bronze can be used if desired.

Foster-Wheeler Corporation has furnished vacuum refrigerating systems for the direct cooling of tomato juice and has also furnished heat exchangers for cooling tomato juice and pineapple juice. According to their engineers, the tubes of the heat exchangers have been made of an alloy consisting of 8 per cent chromium and 18 per cent nickel with less than 0.12 carbon. This alloy has successfully withstood the corrosive action of the organic chemicals encountered.

Corrosion in Dyeing Equipment

Corrosion-resistant materials find many applications in the textile industry, particularly in the dyeing processes. W. K. Russell, of the James Russell Boiler Works Company, manufacturers of dye kettles and similar equipment, states, "Where nickel is applicable but expensive, especially in self-supporting structures or pressure vessels, nickel-clad steel is an ideal material. While the interior of the container will have the pure-nickel finish as desired, the unit as a whole can be designed in accordance with standard steel practice as the tensile strength of the nickel-clad steel and plain carbon steel are approximately the same. The cost of such a unit is a fraction of one made of solid nickel, and is usually not prohibitive.

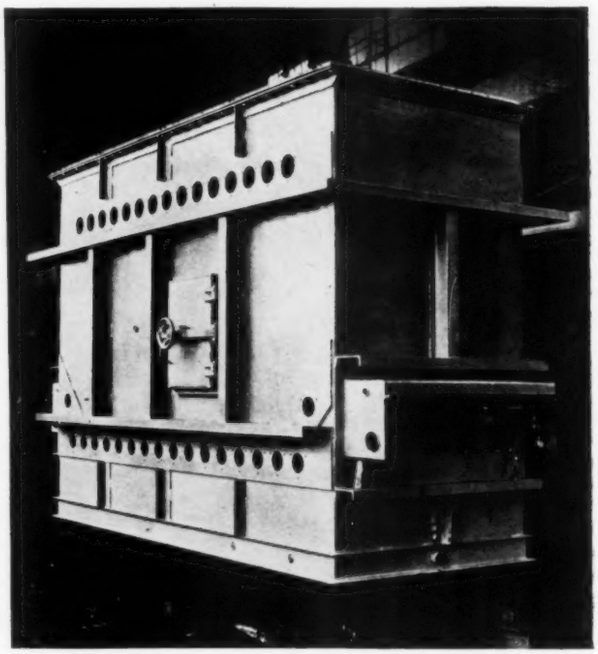
"We have made many dye kettles for textiles where leakage and inability to change colors quickly has been a problem. The nickel-clad kettles can be quickly and thoroughly cleaned which makes it possible for the dye houses to get along with fewer kettles.

"Formerly, lined wooden tubs were used. The light metal lining usually did not fit the wooden backing exactly and there was a tendency to 'breathe' which eventually caused the seams to leak."

The accompanying picture illustrates an "ager" box built recently by the Russell company for a print works. This particular piece of equipment is made of nickel-clad sheets and replaced a cast-iron box of the same size. The cast-iron box had corroded badly under the acid conditions to which it was being subjected, badly discoloring some of the cloth going through it. The box illustrated is approximately 5 ft. wide, 9 ft. 6 in. high, and 14 ft. long. The external bracing is structural steel welded to the shell plate to procure rigidity, a relatively thin nickel-clad sheet being used for the shell. Openings in the shell are protected with sheet nickel where necessary.

As put by Mr. Russell, "Nickel, while excellent in withstanding most acid conditions, is not a 'cure-all' for all corrosive work." Thus we find in this same field a wide use of Monel metal and chrome-nickel steels as well as straight-chromium steels.

For castings that come in contact with free sulphuric acid, sulphur compounds, sulphite soap, acid, lime water and similar liquids, B. F. Shepherd, chief metallurgist of the Ingersoll-Rand Company, specifies a low-carbon, 28 Cr—11 Ni steel. For medium corrosion resistance, such as met with in handling hot oils, a low-carbon 13 per cent Cr stainless iron, with a minimum tensile strength of 100,000 lb. per sq.in., is used. Mr. Shepherd points out that with higher chromium content the steel becomes more difficult to cast and machine, and work hardens under comparatively little cold work, for which reason such castings are used only in special applications. Similarly, 18–8 Cr–Ni castings are used only in special instances, being heat-treated to obtain the corrosion-resistance.



An ager box built by the James Russell Boiler Works out of nickel-clad sheets to avoid discoloration that would be caused by carbon steel

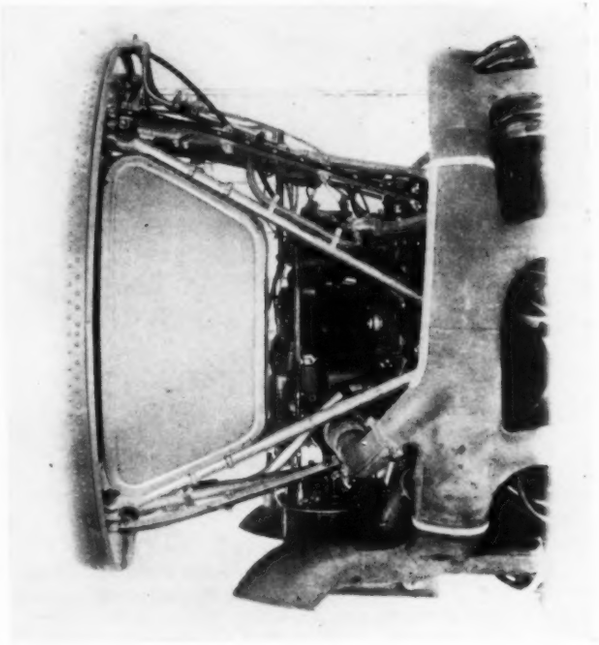
For marine service and for applications requiring only relatively mild corrosion-resistance, an acid-resisting bronze, 88 Cu—10 Sn—2 Pb is usually used. For parts machined out of bar stock and that must

be corrosion-resistant, Ingersoll-Rand uses an 18–8 Cr–Ni steel with 2 per cent silicon added. For mild corrosion resistance, a 12 per cent Cr steel is used, while for rivets an 18 per cent straight chromium steel is preferred because of its ability to take cold working without losing its corrosion-resisting properties.

Extractor Baskets and Evaporators

A 5 per cent Cr steel with ½ per cent Mo is used for castings that must be resistant to mild corrosion and where high strength is required at temperatures in excess of 750 deg. F. This material is not suitable for acid resistance.

Extractor baskets of centrifugal driers are subjected to mild corrosion and high tensile stresses. These latter are not only the result of the centrifugal forces.



Stainless steel is used for the streamlined exhaust collector ring on the engines of the airplanes built by the Northrop Corporation

Great stresses are also caused by out-of-balance loads which tend to distort the baskets while running at high speeds.

E. L. Miller, chief engineer of Tolhurst Machine Works, Inc., states that they use mostly Monel and corrosion-resistant steels for such baskets. These metals have superseded copper because of their greater tensile strength and ease of welding, the greater strength of the material allowing greater loads at higher speeds than would be possible with copper construction.

Similarly, the Sharples Specialty Company, according to Arthur Ayres, uses Monel metal for many of the rotors of their centrifugals, the metal being cold worked to obtain high strength. Mr. Ayres points out that in their experience this metal has been found satisfactory for a good many corrosion-resisting applications, and has also shown considerable ability to withstand erosion.

In the design of large mixing and blending machines as manufactured by the J. H. Day Company, M. R. Sentman points out that formerly such equipment was largely made of ordinary boiler plate. Later, Monel and "stainless" steel came into use. Mr. Sentman also points out that welding this material is now as successful and practical on these newer metals as on ordinary steels. One interesting point that he emphasizes is that in assembly equipment built of "stainless" steel care should be exercised in eliminating hammer blows or molding over forms as is the common practice in copper work. Hammer blows tend to crystallize or harden the material to a point objectionable to machining.

In the design of evaporators for caustic soda, H. D. Grand, president of Swenson Evaporator Company, states that they have used nickel-clad steel sheets extensively, this material having proved satisfactory both from a manufacturing and an operation standpoint. Quoting Mr. Grand:

"Before the use of nickel evaporators were fabricated of cast iron and steel. As nickel became available in tubes and rolled plates, it began to be used more and more until at present most of the caustic evaporators in operation are equipped with nickel tubes and tube sheets, at least for handling concentrations higher than 25 per cent NaOH. Further improvements were made in the steam economy of caustic evaporators and generally tended to subject the materials of construction to higher temperatures and higher concentrations.

"Nickel-clad steel is also indicated for the materials of construction for multiple-effect apparatus which handles caustic concentrations above 30 per cent NaOH. We have also used nickel-clad steel for the inner trough of the Swenson-Walker continuous crystallizers where it replaces steel and is used to avoid contamination of the crystals. Nickel-clad steel has also been used for the walls of the steam baskets of the basket-type vertical-tube caustic evaporators. We are at present fabricating an evaporator of 18–8 Cr–Ni clad steel with 18–8 Cr–Ni tubes and tube sheets. I believe this is the first evaporator of this material to be fabricated in this country. We have also fabricated 18–8 Cr–Ni evaporators where the solid metal was used for the body and heating elements."

Atmospheric Corrosion

The particular reasons for the desirability or necessity of combating atmospheric corrosion cover a wide range. What is of more importance, the required degree of corrosion resistance and the necessary life of the corrosion-resistant surface vary considerably in different applications.

It is generally recognized that electroplatings have a limited life. Although this does not signify that electro or other forms of plating have a short life, on account of the nature of electroplating, its life will be only a fraction of that of the solid sheets of the same material. Much depends on the character of the plating metal and the metal that is plated, and the manner in which the plating is done.

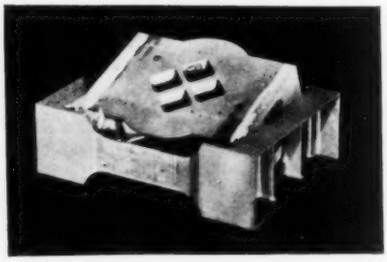
It is unfortunate that some engineers will refrain

from specifying plating for reasons such as given above. There are innumerable applications wherein an electroplated surface protection will outlast the product on which it is used. Any additional expense to accomplish more than this is money wasted.

In the Toledo scales manufactured by Toledo Precision Devices, Inc., a flexible steel ribbon is used to transmit the motion from the cams to the indicator mechanism. Two kinds of materials are used for these ribbons. Because of their corrosion-resisting property, ribbons of chrome-nickel steel are preferred, but the cold-drawing properties of the metal present some difficulties. Ribbons of this material rolled to a thickness of 0.004 in. are used and some ribbons 0.007 in. thick. The other material is Swedish spring steel rolled to thicknesses of 0.002 in. or 0.004 in. for different applications. To provide surface protection against corrosion, the ribbons of Swedish spring steel are cadmium plated. They are then given a moderate heat-treatment in order to remove any possible embrittlement resulting from the plating process.

This same company, as reported by W. J. Burr, metallurgist, makes extensive use of chromium plating, both the ornamental-type plating and the hard-chromium plate for wear resistance.

According to one of the metallurgists of the Chrysler Motor Corporation, the manifold studs on their engines were made formerly of a chrome-nickel steel. They now use a 0.35 carbon steel, chrome-plated to resist corrosion. The reason for this change was because the corrosion-resistant steel did not have a sufficient chromium content to be fully rust resisting and the bolts were not as strong as those made of 0.35 carbon steel and heat-treated.



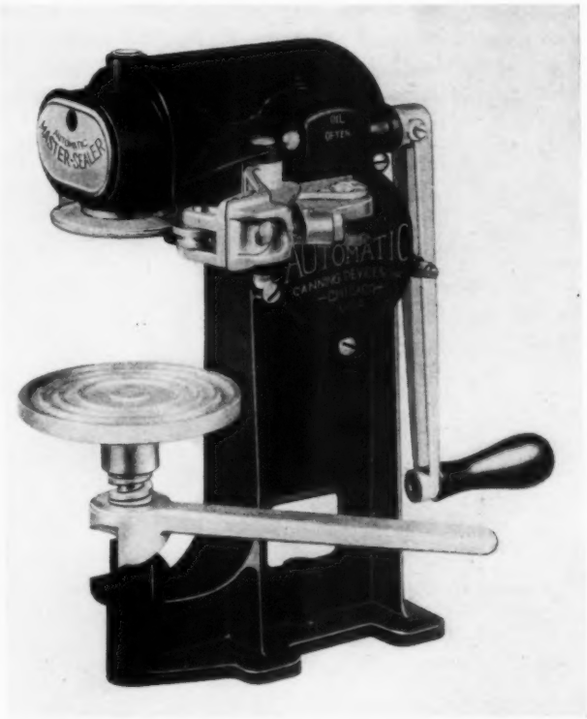
Aluminum valve and valve guides for valves built by the National Pump Corporation are given the anodic treatment to increase the wearing qualities

Surface Finishes for Appearance

According to W. E. Blewett, Jr., assistant to the president of the Newport News Shipbuilding & Drydock Company, for marine work, where atmospheric corrosion conditions are probably most severe, chromium plating has replaced nickel plating because of its longer life.

To procure both corrosion resistance and a pleasing surface finish, G. H. White, chief engineer of the Castype Corporation, states that they cadmium plate practically all of the stampings used in their simplified typesetting machine for office use. Stanley R. Shelmire, chief engineer of the Standard-Trump Company, specified cadmium plating for an unusual reason. One of the units of the circular knitting machine of this company consists of a number of telescoping shafts. To improve the surface conditions and thereby the lubrication, the hollow shafts are cadmium plated.

Innumerable other instances of the application of chrome, nickel and cadmium electroplating could be cited. In general, it is the practice in automotive design to cadmium plate for rust protection and chromium plate on nickel for rust protection and decorative effects. L. B. Sperry, chief engineer of the Tractor Division of the International Harvester Company, states, "through cadmium and chrome plating we have endeavored to safeguard important parts against excessive corrosion."



Difficulty in keeping aluminum looking clean and attractive can be avoided by anodic treatment whereby the aluminum surfaces can be given lasting color finishes.

For cylinder head casings and piston valve casings, chromium plating has been used on some of the locomotives of the Union Pacific Railroad. The object is to obtain a good appearance and a surface that will not rust or deteriorate. Plating is not entirely satisfactory because of the abuse to which the casings are subjected when taken off and dropped on the ground. Corrosion-resisting steel has also been used and "stainless-clad" sheets are being tried out for this service. One of the difficulties appears to be trouble with the deep-drawn casings becoming "rippled" in the drawing process, apparently because of lack of pressure in the pressing operation.

For products made of aluminum, there is available the anodic treatment whereby the aluminum can be given various colors. In addition, this process has a hardening effect on the aluminum surface.

In the field of novelties such as compacts, cigarette cases, vanities and similar products, the J. G. Pilcher

Company uses this process, Alumilite, to secure attractive finishes. Attractive finishes and designs are obtained in either one or two colors and because the coating is an integral part of the base metal there is no danger of scratching or chipping.

Alumilite coating is also used by the National Pumps Corporation on the valve and valve guide in one style of their meters. In this application the coating serves two purposes, namely, hardening of the bearing surfaces of the valve and the guide to resist abrasion and also as protection against surface disintegration.

Toledo Precision Devices usually uses white-surface steel sheets for the dial charts of their scales. Charts for cylinder scales are anodic-treated aluminum sheets, the printing being done directly on the oxidized aluminum surface with a clear lacquer coat put on afterwards for protecting the printing. The special chart used on the printing mechanism which automatically prints weight tickets is a sheet of duralumin with the figures etched in relief to a depth of 0.006 in.

In the design of the electric dishwasher manufactured by The Conover Company, a pump cover apron is located in the bottom of the tub where it is subjected to the action of mild acids and alkalies. According to Edgar S. Stoddard, chief development engineer of The Conover Company, this part was made originally of copper. Colored salts such as copper basic carbonates formed on the surface of the copper giving an unsightly appearance.

In searching for a solution of this problem, Mr. Stoddard states, "Our choice was limited to materials such as nickel or corrosion-resistant steel because of the necessity of this part withstanding the action of mild acids and alkalies. We selected corrosion-resistant steel because nickel would tend to stain more readily and require more frequent cleaning under those service conditions."

Instrument parts as manufactured by the Pioneer Instrument Company are generally of brass with a nickel flash. For parts requiring greater strength, 18 Cr—9 Ni, with the addition of 0.12 Se (Carpenter stainless No. 8) is used. Two distinct advantages of this material are that it is non-magnetic, and is also easy to machine.

When the Problem Is to Prevent Erosion

SHIP propellers, water turbines, centrifugal pumps, and all types of liquid impellers operating at a relatively high speed present the problem of selecting a material to resist both erosion and corrosion. As an additional factor, in many of these applications the effects of cavitation also enter into the problem.

Cavitation takes place when the churning of a high-speed propeller or impeller causes cavities or "air bubbles" to form in the liquid. These "bubbles" are air or gas at a low pressure, in some instances approaching a vacuum.

In quoting the results of tests conducted by other investigators, T. F. Hengstenberg, of the Research Laboratories of Westinghouse, states that pressures of the order of 140,000 lb. per sq.in. may result from the hammer effect of the collapsing water cavities. These pressures are, of course, localized, their effect being to pit the surface of the metal.

Cavitation is not confined to high speeds. Air leakage through the packings of a centrifugal pump, operating with a suction pressure below atmosphere, will tend to set up cavitation even at moderate speeds.

Water impellers and ejectors such as used on electric dishwashers are subjected to both corrosion and erosion. According to Edgar S. Stoddard, chief development engineer of The Conover Company, "These parts should be formed quite accurately—the shape of the impeller is particularly important on account of the effect of slight changes in shape on the efficiency. The parts must have a smooth surface and must not rust or corrode under the influence of warm mild acids, alkalies, and moist air.

"Previously we used vitreous enameled iron and sand cast metals, but we experienced difficulty in preventing distortion of these parts in the finishing processes. We also used 'stainless' stampings, but found that the shape was not easily produced with uniform curves on account of the spring in the metal.

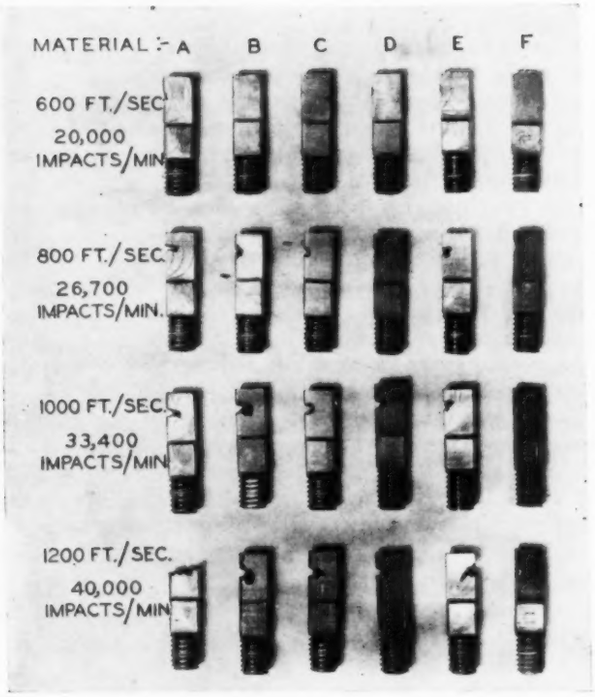
"Die-castings seemed to offer the best solution to our difficulties. The lower melting metals did not give us sufficient strength and resistance to corrosion, hence we selected aluminum bronze.

"The reduction in the number of rejects and increased life of the parts have made the change to this material worth while, although the unit cost is somewhat greater than when other materials were used."

Materials for Turbine Blades

What is perhaps one of the most complicated problems in the selection of materials is that encountered in steam turbine blading. Years ago when steam pressures, temperatures and velocities were relatively low, corrosion was the only factor that had to receive close attention. Even this was not a serious problem because as long as the machine was running the blades were kept dry by the heat of the steam. Only during shutdowns could there be corrosion, which would be accelerated by leakage of steam past the throttle valve. In some installations, acidic boiler-feed water would cause complications. Acid carried over into the turbine with the steam would condense on the blades, thus corroding them.

In recounting the development of turbine blade materials, L. N. Mochel, chief engineer of turbine design for the Westinghouse Electric & Manufacturing Com-



Results of tests on the erosion-resisting properties of six different metals as tabulated below.

Specimen	Material	Hardness Vickers Pyramid Number
A	Plain 0.40 Carbon Steel	145
B	2.20 Ni—12.0 Cr Steel	204
C	0.10 Ni—12.0 Cr Steel	258
D	Nickel Steel	248
E	8.0 Ni—20.0 Cr	260
F	Casehardened—Nitrided	

pany, stated that up until about 1910 plain carbon steel was used for the blades. Speeds and steam temperatures began to increase at about that time, and much attention was then given toward the development of corrosion-resistant steam turbine blades. Various materials were tried. In about 1913 or 1914, nickel came into use. These nickel blades were forged, machined out of bars, and also extruded. Over a long period of service they proved able to resist the erosion and corrosion and also maintained the required strength at the temperatures under which they operated.

Mainly because of its relatively better workability, 5 per cent nickel steel came into use in about 1915. It is interesting to note that the material was first imported from France. The corrosion resistance of nickel steel is not nearly as good as that of pure nickel, but the material served its purpose under the then existing conditions of temperature and speed. The material is still in use today but is largely restricted to the impulse blades.

As speed and steam pressures increased further, the erosion problem became of greater importance. Steam condensation in the lower stages of the turbine forms globules of water. One edge of the blade, traveling at a high linear speed, hits these globules of water. As reported by T. F. Hengstenberg, of the Westinghouse Research Laboratories, at a velocity of 1,000 ft. per second the theoretical pressure built up on the surface of the metal upon impact with drops of water has been calculated by several investigators to be from 50,000 to 70,000 lb. per sq.in.

Results of Erosion Tests

In the accompanying photograph are shown the results of tests conducted in the Westinghouse Research Laboratories on six different materials. The specimens are inserted in the rim of an impeller disk driven by an electric motor through a suitable step-up gear box. Two fine jets of water, parallel to the impeller shaft, cross the path of the test pieces at diametrically opposite points. Thus each test specimen strikes an unbroken jet of water twice in each revolution of the impeller. The dynamically balanced disk revolves at 20,000 r.p.m, for a maximum peripheral speed of 1,200 ft. per sec. The table accompanying the illustration gives the list of materials tested, the illustration showing the relative results. It will be noticed that the nitrided steel specimen withstood the erosion in a remarkable manner. However, once the thin case has been worn through only the soft matrix remains, which has relatively little resistance to erosion.

According to Mr. Mochel, at present one of the most satisfactory methods of combating this erosion is to shield the blade with a layer of Stellite. It would not be possible to make the whole blade out of Stellite because the material is too brittle and too costly. Engineers are still looking for a single material that will have all of the properties for turbine blading including that of erosion resistance.

Today practically all steam turbine reaction blades are made of 11½ to 12½ per cent chrome steel and heat-treated to give them the highest physical properties. The blades are machined out of solid bar stock, instead of being forged, a production method made possible by the improvement in milling machine practice. One great advantage of this straight chromium steel is that the blades will not rust during a shut-down period.

Other materials that have been experimented with for turbine blades include phosphor bronze which was used in 1912. Manganese bronze has proved superior to phosphor bronze, and the former material is still largely used in the low-pressure stages. For the intermediate stage blading, some engineers specify Monel metal.

Propellers, Pump Runners and Hydraulic Turbines

In explaining the requirements for the propellers of their outboard motors for racing speeds, R. Karasinski, chief engineer of the Johnson Motor Company, states that the material used must not only be corrosion and erosion resistant but must also have high strength. The propeller blades must be as thin as possible in order to reduce the underwater resistance and to obtain maximum propeller efficiency. At the same time, these particular blade sections must be strong enough to withstand the bending moment set up by the propeller thrust. Die-cast aluminum bronze with its high-tensile strength allows using thinner propeller blade cross-

section and thereby provides high propeller efficiency. The material also withstands corrosion, erosion and the effects of cavitation to a high degree.

Marine propellers such as used on ocean liners are usually made of manganese bronze.

Runners for water turbines are subjected to service conditions quite similar to those of propellers. Great resistance to pitting of the metal because of cavitation is required. Formerly, carbon steel was used for this service. According to Elov Englesson, chief engineer of A-B Karlstads Mekaniska Verkstad, Kristinehamn, Sweden, this company used chrome-nickel steel for the runners of the turbines which they built recently for Russia. This material was adopted after extensive tests had proved that chrome-nickel steel had the greatest resistance to corrosion and to pitting caused by cavitation.

One of the largest single-runner Pelton-type waterwheels ever built in England uses chrome-nickel steel for the runners.

Impellers of centrifugal pumps operating at normal temperature and used for condensate and similar purposes are made of acid-resisting bronze. In pumps used in connection with processing rayons, wherein the impeller is subjected to alkaline and acid conditions, they are made of 18-8 Cr-Ni steel, according to H. G. Conkey, engineer of the Cameron Pump Department of the Ingersoll-Rand Company. George Shaw, engineer of the same company, states that they use a 12-15 per cent chrome steel for the impellers of oil pumps for cracking stills. These are 10-stage high-pressure pumps operating at 750 deg. C, under a pressure of 1,500 lb. per sq.in., having a capacity of 38,000 gal. per hr., and requiring 1,000 hp. for driving them. For such service, the chrome-nickel steel would not be satisfactory as it is subject to temperature embrittlement.

For hydraulic plug valves for pressures up to 1,500 lb. per sq. in., Yarnall-Waring Company uses a cast Nitralloy steel alloyed with vanadium and chromium rather than aluminum and chromium. These valve plugs have to withstand both corrosion and erosion. According to the experiences of this company, the alloy containing vanadium and chromium gives a nitrided surface that does not blister. Incidentally, soft red brass is used for the sealing bushings, the valve bodies being of bronze and the wire springs used in the valve being of phosphor bronze.

In the Viscolizer, built by the Cherry-Burrell Corporation, milk, cream, tomato juice and similar liquids are forced under a pressure of 2,000 to 3,000 lb. per sq.in. through the viscolizing valve. H. S. Fielder of that company gives the information that the valve seat and spacer used in the valve are of cast Stellite, ground to shape. This material is used to resist both the corrosive action of the liquid and also the erosion. Bronze is used for the valve body.

Subjected to somewhat similar requirements, the valve seats of the pump that forces the liquid through the viscolizing valve are of chrome-nickel steel, pressed into the cylinder block. Erosion conditions here are not quite so severe as in the viscolizing valve, corrosion resistance being the principal factor. The valve springs are also made of chrome-nickel steel wire.

Erosion of nozzles such as those used in oil burners has always presented a vexing problem. In the Quiet May oil burner, the May Company uses sapphire jewels for the nozzle channels through which the oil passes. It is reported that another company has used diamonds for a similar purpose. The small diameter of these orifices makes the problem complex.

Combating Wear and Abrasion

IN WEAR and abrasion, the severity and character of the service conditions vary over a wide range. Each type of service calls for certain physical characteristics in the material that is to be used. Other factors, such as impact, are sometimes present also.

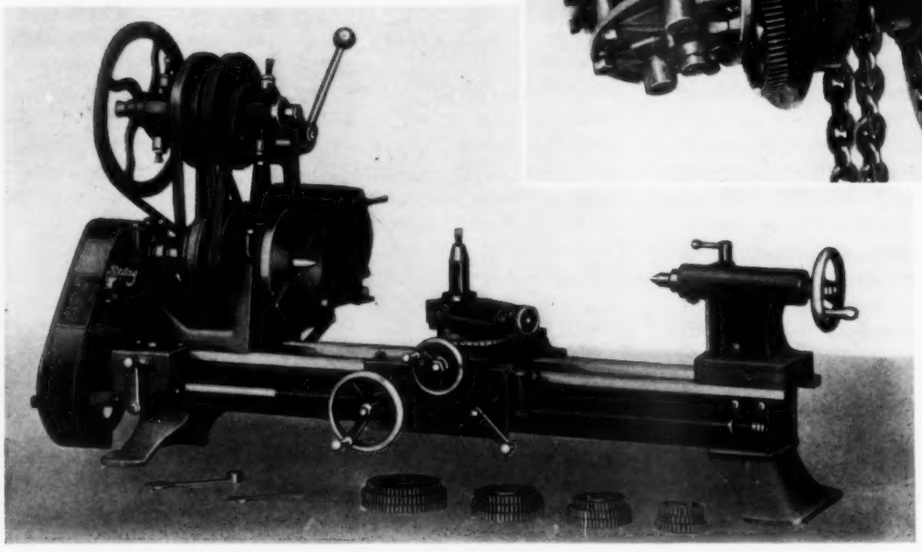
For the timing gears of the high-speed diesel engines manufactured by the Baldwin-Southwark Corporation, a special nickel steel, forged and hardened, is used.

Gears used in the circular knitting machines manufactured by the Hemphill Company are usually steel meshing with bronze pinions, according to Robert H. Lawson, chief engineer of that company, who also disclosed an interesting situation or problem concerning the materials used in a right-angle worm drive. Hardened steel worms had been used, but these warped in the hardening process. Grinding was expensive. At the same time, great accuracy was required in the worms because of the necessity of having a definite and constant angular velocity ratio between the two shafts. The total variation in the worm profile was limited to 0.005 in. To obtain good wearing qualities and at the same time avoid possible warping, one worm was made of a hard, tough steel, not hardened, hence no possibility of warping. The other worm was made of bronze containing a high proportion of lead and having an extremely hard surface texture. The lead content of the bronze was favorable to lubrication. This combination of bronze and hard, tough steel has worked satisfactorily.

Open Gearing for Heavy Duty

Illustrating the effects of heat-treatment, E. S. McPherson, metallurgist of Hupp Motors relates that for transmission gears he formerly used S.A.E. 5150 steel (0.50 C., 0.70 Mn, 1.0 Cr.). These gears were heat-treated in various manners, namely, heating in an electric furnace to 1,525 deg. F., and soaking in a cyanide bath at the same temperature, followed by a quench. Later the heating was done entirely in a cyanide bath at 1,525 deg. F., and then quenched. In each instance, the material pitted under heavy load. The material was then changed to S.A.E. 4615 steel (1.71 Ni, 0.25 Mo, 0.15 C.). These gears were given two heat-treatments, one to refine the case and the other to toughen the core. The improved material permitted a reduction

All but two of the gears in this hoist built by the McCollum Hoist & Manufacturing Company, are zinc die-castings.



Bench lathe built by the Atlas Press Company wherein all of the gears and many other parts are zinc die-castings

in the size of the gears for equal loads and the effect of the molybdenum was to give a fine grain structure, the material responding readily to heat-treatment and giving a tough core.

Exposed gearing in construction equipment presents a troublesome problem. It is difficult to maintain proper lubrication, and it is impossible to keep sand and grit out of the gears. Referring to the construction equipment manufactured by the Insley Manufacturing Company, A. C. Rasmussen states:

"For exposed gearing we have been trying to find a satisfactory combination of materials to give the desired wear life. It is well known that steel on steel cuts quite easily, and this has been our experience. Hardened steel against cast iron wears well, but lacks strength and shock resistance. Recently we have made several installations of hardened steel pinions meshing with Promal gears. This is a 'processed malleable' iron. It has an exceedingly high resistance to impact and likewise seems to have considerable resistance to surface breakdowns, indicating possible better wear life."

Zinc Die-Castings for Strength and Wear

Zinc die-castings are not commonly thought of as being wear resistant, yet they do possess this property to a relatively high degree, as is evident by recent applications of this material. Probably one of the most outstanding designs incorporating zinc die-castings for parts that must have considerable wear resistance is the lathe manufactured by the Atlas Press Company. Quoting J. G. Collins, chief engineer of that company:

"Our object was to build a lathe which we could retail for less than $100 and one that would do satisfactory tool-room work. In seeking methods of production to reduce costs we ran across the die-cast metal known as Zamak-2. We gave this metal a thorough trial and were astounded at the results. Accordingly, we have adopted this Zamak for use in some forty-five parts on the lathe, such as gears, switch boxes and other small parts which, although light and not receiving particularly heavy service in the ordinary use of the lathe, would be more expensive if machined parts were used.

"This material has proved considerably stronger than cast iron, and reports from users of our machines indicate that the material is standing up well in service."

Wear on Scale Pivots

Toledo Precision Devices, Inc. have undertaken extensive tests in the investigation of the deformation of pivots made of various materials. The information given here was furnished by W. J. Burr, metallurgist of that company.

Pivots tested were made with a 70-deg. angle and a sharp knife edge not exceeding 0.0002 in. in width. Bearings were of the 120-deg. V-type with an extremely small radius in the bottom of the groove. As a general statement, loads on the pivots upset their edges approximately in proportion to the hardness of the material. Bearings, if a little harder than the pivots,

show but slight marking. Wear on the knife edge occasioned by its oscillation through an angle of 2 deg., and even up to 3 deg., had but little effect even over a prolonged test of a quarter-million oscillations. Oscillations through an angle greater than 4 deg. resulted in rapid wear accompanied by chipping of the material.

As to the relative merits of the different materials tested, 1.00 C steel functioned quite satisfactorily. Carburized and hardened S.A.E. 1020 steel (0.20 C, 0.45 Mn) and also the high-manganese, low-carbon type of carburizing steel withstood the static loads extremely well but had more tendency to chip under oscillation. Alloy carburizing grades, notably S.A.E. 6115 (0.95 Cr, 0.17 Va), were better with respect to chipping. High-carbon chrome-molybdenum steel stood up exceptionally well, somewhat better than straight carbon steel. At comparable hardnesses, straight chromium steel functions about the same as plain carbon steel. Medium-carbon 13 per cent chromium steel, being softer than the 18 per cent chrome—1 per cent carbon type, did not give as good service as the latter.

Pivots made with welded-on edges of other special non-ferrous alloys of the cobalt, tungsten, chromium type, chipped under heavy loads. Nitrided pivots were unsatisfactory on account of chipping, though these bearings were found exceptionally good for the lighter and intermediate loads. This is especially so if the steel nitrided is of the special alloy type that permits of nitriding temperatures without softening the core.

Wear in Fine Instruments

Wear resistance is not confined to the heavy machine elements. In the design of electrical measuring instruments, C. Anderson, meter engineer of the Westinghouse Electric & Manufacturing Company, explains that the moving element must respond with the smallest possible amount of friction. Bearings for such applications are usually of the pivot type with a hardened and polished steel pivot of small radius bearing against the surface of a small hollow cup. Sapphire bearing cups, in use for a number of years for this purpose, have recently been replaced with Nitralloy bearing screws. It is claimed by Mr. Anderson that these Nitralloy bearings can be manufactured in one piece on automatic screw machines and after polishing, nitriding and cleaning, the surface produced attains a high finish, has great wear-resistance, does not corrode and is approximately as hard as sapphire.

These Nitralloy bearings cost less than sapphire, and the bearing will withstand severe shocks and vibrations that would fracture a sapphire bearing. Not only are the sapphires expensive, but they also require a complicated design for mounting as allowance must be made for expansion and variation in dimensions.

Stellite and Nitriding for Wear Resistance

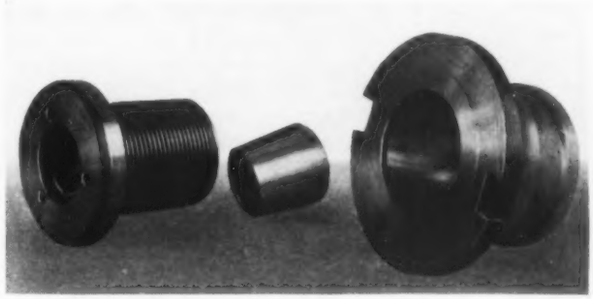
The use of Stellite for wear resistance on steam turbine blading has already been mentioned. Westinghouse company also uses Stellite for inserts for pantograph shoes.

On Landis grinders, the back-rest shoes which support the work against the pressure of the wheel are a fine example of metal subjected to wear. C. L. Ott, assistant chief engineer of this company pointed out that on account of the combination of high pressure and velocity, wear conditions are severe. For this service, the bearing shoes are either coated with Stellite or a hard white cast-iron insert is used. On this same line of machines, the grinder beds are made of semi-steel with chilled ways for wear resistance.

For wear resistance, according to H. H. Ashdown, metallurgist of Westinghouse, this company does a great deal of nitriding. One point strongly emphasized is that the nitriding steel must be heat-treated above the nitriding temperature, which is approximately 1,070 deg. F., in order to prevent the distortion of the metal during the nitriding process. According to Mr. Ashdown, there will be absolutely no distortion if the heat-treatment is carried on at a temperature higher than the nitriding temperature. Properly nitrided surfaces will retain their hardness up to a temperature of approximately 1,000 deg. F., which is a dull red heat.

In the automotive field, cooling water pump shafts have been nickel plated or chromium plated not only for corrosion resistance but also so that the surface of the shaft shall remain smooth and thus avoid rapid wear of the packing. More recently, these shafts are being made of nitrided steel which answers the same purpose. In this same field of design, one of the metallurgists of the Chrysler Motors Corporation, states that carburized steel was formerly used for the valve lifters but this has now been changed to chilled cast iron, this latter material being harder and giving a longer life.

Another use for Nitralloy is cited by Lev A. Trofimov, development engineer of the Electric Controller & Manufacturing Company. He states, "We use Nitralloy pins and bushings for the main arm pivots of our d.c. and a.c contactors. This is because the pivot has little chance to be lubricated, and Nitralloy stands up well without much attention, both from the point of wear and corrosion."



High temperature and corrosive conditions are met in a cracking still pump, some parts of which are also subjected to heavy wear. As manufactured by the Ingersoll-Rand Company, the balancing drum and bushings are of Nitralloy, and the balancing sleeve (to the right) is made of high chromium, high-carbon tool steel

Nitrided Surfaces Do Not Crack Readily

Concerning nitrided cases, it seems to be a prevalent thought that the nitrided case is extremely brittle. Contrary to this general opinion, according to Mr. Ashdown, nitrided surfaces do not crack readily. As an

Of recent years, special alloys have been adopted to resist the wear, impact and abrasion to which construction equipment is subjected

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illustration, $\frac{1}{8}$-in. diameter rods that have been nitrided will not crack even when the rod has been bent to a hairpin shape. If the material has been properly heat-treated before nitriding, no surface cracks will be visible. It is true that the case itself is brittle, but if the core is ductile the case will bend with the core. On the other hand, if the core is hard the case is more apt to crack.

Bearing out the above statement concerning the ability of nitrided cases to stand up against cracking is the interesting design of guide shoes used on the elevators of one of the leading manufacturers of such equipment. These guide shoes run on rails, making contact both with the top surface of the rail and the side surfaces of the rail. The wear resistance problem was solved by using strips, $\frac{1}{16}$ in. thick, of nitrided steel, these strips being backed up by zinc die-castings which in turn were held loosely in the guide shoe with a spring behind the die-casting. With this arrangement, the nitrided strips were relieved of impact and shock which was absorbed by the spring backing of the zinc die-casting. These guide shoes have stood up a number of years against the high rubbing speeds encountered.

A recent development pointed out by engineers of Westinghouse is that of cast-iron alloys suitable for hardening to give good nitriding characteristics similar to those of steel. This is obtained by the addition of aluminum, chromium, nickel and molybdenum in the cast iron. Such "nitrided" surfaces are considerably harder than a chilled cast-iron surface, the hardness being as high as Vickers Brinell 750.

Marmon automobile engines use nitrided cast-iron cylinders, preliminary tests of which have shown that after 60,000 mi. there has been no significant amount of cylinder wear. Hupp Motors use nickel-chrome iron for the cylinder blocks, this giving a smooth bore and hard wall, with high wear resistance. Although this material is harder to machine, it does not present any particular difficulties.

For wear resistance, wheels of the hand-power cranes built by the Euclid-Armington Company are made of Meehanite, a high-test cast iron. In the experience of G. H. Schroeder, chief engineer of that company, Meehanite wears better than either gray iron or steel and will withstand the normal amount of pounding to which the wheels of these hand-power cranes are subjected. Therefore there is no danger of the metal cracking as the result of impact in this particular service. The engineers, however, do not use Meehanite for their power cranes. It has been their experience that the machining speed of Meehanite lies about half way between that of gray iron and steel, and the material has the additional advantage that it is remarkably free of blowholes.

Primarily for wear resistance, Meehanite is used for light-duty cams on the knitting machines of the Standard Trump Company, according to Stanley R. Shelmire, development engineer of that company. They use tool steel for the heavier duty, such as needle cams.

With reference to the non-ferrous alloys used by the Landis Machine Company, in their experience ordinary red brass or bronze gears running in an oil bath would flake. Therefore these gears are now made to specifications of 87.5 Cu, 11.0 Sn, and 1.5 Pb. Threaded feed nuts and bushings are made of 80 Cu, 10 Sn, and 10 Pb. Small pieces such as operating levers wherein both strength and bearing properties are required are now made of manganese bronze in preference to the softer brass or cast iron.

Materials for Abrasion Resistance

Abrasive wear is one of the biggest problems faced by designers of construction equipment. With reference to this, A. C. Rasmussen, chief engineer of the Insley Manufacturing Company states:

"For dipper teeth and cutting edges we have been using cast manganese-molybdenum steel, heat-treated, hardened and drawn. The cutting edges and points are hardened to between 450 and 500 Brinell, but the body of the casting back of the edge is drawn so that where bending stresses are at a maximum the hardness will be in the neighborhood of 200 to 250 Brinell.

"For crawler shoes we also are using heat-treated alloy cast steels, hardened and drawn. Crawler rollers and end tumblers are made of alloy steel. These parts are given a double heat-treatment so that the hubs and spokes are strong and tough, yet soft enough to be machinable, while the rim on which the rolling occurs is made as hard as possible to withstand abrasion.

"Stellite has been used for the surfacing of latch plates and latch points to increase the resistance to wear. Likewise, it has been applied to dipper teeth. The success of such applications depends largely upon using the proper method of applying the Stellite."

The problem of wear and abrasion resistance in the design of sand and dredging pumps is considerably different from that of steam shovels. This is strikingly brought out by the comments of V. J. Milkowski, chief engineer of dredging machinery, Morris Machine Works, who states:

"The particular difficulty that we have in the construction of our sand and dredging pumps is to furnish parts to resist abrasion, and in some instances both abrasion and corrosion. For straight dredging work wherein the abrasion is extremely severe and the material handled contains a large amount of stones and boulders which produce considerable impact and cold working on the pump parts, manganese steel is without doubt the best material. It is extremely tough and becomes hardened under cold working and impact.

"On the other hand where the material pumped consists exclusively of fine sharp particles which do not produce cold working and impact, manganese steel does not give good service. For such conditions, we use our Flintmetal or Flintalloy. The first of these is a hard, low-chrome iron, and the second is an alloy steel which when heat-treated and hardened resists abrasion to a high degree. Both of these metals are, however, extremely brittle when made very hard. In the case of Flintalloy, the hardness and brittleness can be controlled with heat-treatment, and some of the extreme hardness can be sacrificed in order to obtain greater strength and toughness in the casting.

"In the pumps which we furnish for the Chance process of coal cleaning, the pumps are required to circulate a mixture of fine, sharp sand and water. Usually a percentage of acid finds its way into this water, creating the problem of providing a metal that will resist both corrosion and abrasion. For this service we use Flintmetal with 18 per cent Cr, and 8 per cent Ni, which is an extremely hard and practically stainless iron. This metal is used for the shell, impeller and the disk or the disk liners, these being the parts of the pump subjected to the corrosive and abrasive action."

M. F. Lowry, of the Engineering Department of The Hoover Company, cites an interesting application of materials for resisting abrasion as follows:

"Another development in which you may be interested is that of a sand chamber liner for our heavy-duty commercial machine (vacuum sweeper), Model 900. It has been found that in certain localities trouble is sometimes experienced on account of the sand-blast action wearing holes. By the use of a sand chamber liner in which a section of rubber is sandwiched and vulcanized between two thin steel plates, we have been able to obtain from three to four times the resistance to this sand-blast action."

Meeting the Requirements of High Stresses, Impact and Fatigue

WHEN it is considered that failure of a material may occur either through fatigue, direct tensile stresses or through plastic flow of the metal or temperature embrittlement, the term "high-strength material" has in itself little significance. It is therefore necessary to state the type of material failure that is to be avoided.

During the past decade it has been clearly demonstrated that most of the mechanical failures are the result of repeated stresses, or fatigue as it is called. Such types of failures are particularly prevalent when in combination with concentrated stresses. In turn, the degree of stress concentration is largely affected by properties of the material other than its ultimate strength or yield point. Ductility of the metal affects greatly the degree of stress concentration under given conditions.

Details of the design probably play a larger part in fatigue failures than is generally recognized. As pointed out by R. E. Peterson, of Westinghouse, a great deal of difference in the strength of steel shafting is caused by the method of milling the keyways. A shaft with "sled runner" milled keyway is approximately 25 per cent stronger than if the shaft were milled with an end mill.

Mr. Peterson also points out one of the peculiarities of medium carbon steel wherein the carbon content is approximately 0.45. Up to a certain point, the fatigue strength increases with increased temperature. This is strikingly demonstrated when a test specimen is heated. The fracture will not occur at the hottest spot.

According to H. H. Ashdown and D. F. Miner, metallurgists of Westinghouse, ordinary motor shafts are made of 0.35-0.50 carbon steel. For heavy-duty motors such as for rolling mills, the shafts are usually a chrome-nickel alloy containing 1½ per cent Ni and about ½ per cent Cr. This is general practice. When motor shafts of exceptionally high strength are required, 0.32 to 0.50 molybdenum is generally added, the shafts being quenched and drawn.

Parts Subjected to Repeated Stress

Connecting bolts for highly stressed shafts and couplings are of Cr-Ni-Mo steel, quenched and drawn. These bolts have a high fatigue resistance and a high impact resistance, as evidenced by their high ratio of yield point to ultimate strength. This same material is also used for the tiebolts for built-up generator rotors.

According to the same engineers, spring material, which must have a high resistance to fatigue, is usually 0.80-1.00 carbon steel with close attention given to get-

ting the steel free of a decarburized surface. Many spring failures, in the opinion of these engineers, can be ascribed largely to the decarburized surface of the material which is extremely favorable for starting fatigue cracks. The best springs are now made of wire that has been ground to get rid of the decarburized skin.

For the high-speed diesel engines built by the Baldwin-Southwark Company, according to G. B. Jack, consulting engineer for that company, the valve springs are made of a chrome-vanadium steel that retains its fatigue strength at the relatively high temperatures encountered. These springs are heat-treated in a reducing atmosphere after they have been formed, care being taken that there is no decarburizing or oxidation on the surface. As also stated by Mr. Jack, this is extremely important as surface oxidation cuts down the endurance of the springs to a considerable extent.

Recently, beryllium copper has been made available commercially, one of the claims for that material being its high fatigue resistance. Although it is too early to secure numerous examples of applications of this material, Jackson Burgess, development engineer of the C. F. Burgess Laboratories, reports the results of some interesting tests. In their micro-switches, which actuate upon a movement of only 0.001 in. of the "pushbutton," it was necessary to secure a design of spring and select a material that would give long life. The flat spring used in this device is continuously under both compression and tension, this imposing a severe duty on the metal.

After having experimented with phosphor bronze and numerous other materials for these springs, beryllium copper was finally adopted. Phosphor-bronze springs lasted an average of 600,000 operations of the switch, with a maximum of 800,000 operations. Two beryllium-copper springs of the same design are now under test and have operated 13,000,000 times without breaking. The springs were given a heat-treatment for one hour at 275 deg. C.

Materials for Locomotives

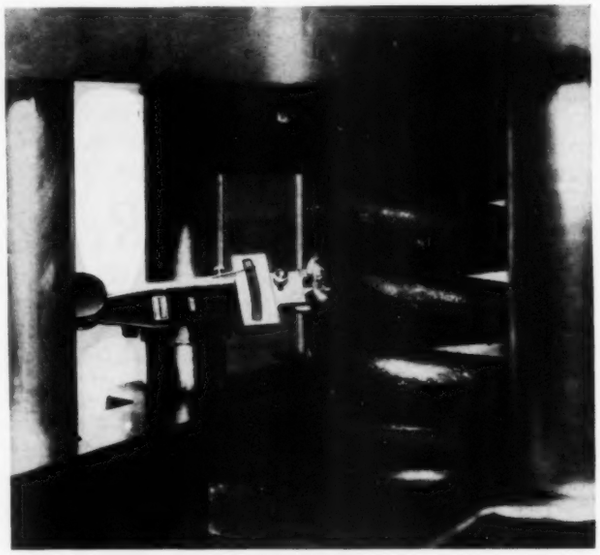
The first high-pressure locomotives built in this country were those designed for the Delaware & Hudson Railroad by John E. Muhlfeld, consulting engineer. He is also the designer of the new D&H locomotive, "L. F. Loree," the first American locomotive to use poppet-type valves. This locomotive operates at 500 lb. per sq.in. boiler pressure and is triple expansion, having one 20-in. high-pressure cylinder, one 27½ in. intermediate pressure cylinder, and two 33-in. low-pressure cylinders. It represents the most advanced design of American locomotives.

Selection of materials for locomotives is a complicated problem involving weight, strength, resistance to fatigue, strength at high temperature, creep resistance and resistance to corrosion, pitting and grooving. Briefly summarizing the situation, Mr. Muhlfeld states:

"In my opinion, there is no question that nosing, fore and aft vibrations, and side swaying of a locomotive are the result of track and rail conditions, unbalanced reciprocating forces, and wheel and rail clearances. Deficiency in counterbalance results in hammer blows on the rail. Dynamic augment is caused by excess balance on account of the reciprocating weights and to the component of the piston thrust. Track rail pressure from this last cause can be reduced somewhat by the use of longer main rods.

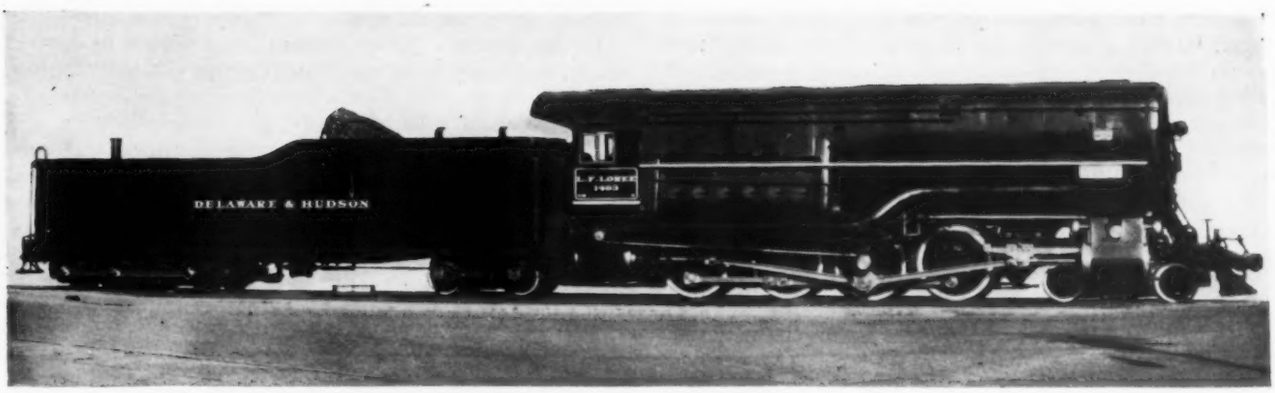
"All revolving and reciprocating parts that must be counterbalanced should be designed to the minimum weight consistent with strength by the use of high-elastic limit, tough, ductile material. This applies equally well to all other unsprung parts such as driving axles and wheel centers. Furthermore, in view of the axle load limitations of existing track and bridge structures, both the total and detail weights of locomotive boiler, chassis and machinery must be reduced to the minimum. This applies especially to the elimination of all unnecessary leading and trailing truck or non-productive wheels and to the unsprung weights in driving axles, wheel centers, main and side rods, and to the other revolving and reciprocating parts.

"As yet, alloy and heat-treated steels, when subjected to repeated loads and high pressures and temperatures, have not demonstrated the anticipated reliability, durability and resistance to fatigue, surface checking, progressive fracturing and failure. The magnetic treatment of ferrous metals, now being experimented with, may be able to effect such changes in the sub-atomic structures as to produce more satisfactory results. In the meantime, service tests of high-elastic limit, low carbon, high manganese, steel castings have shown remarkable resistance to stress, surface checking and progressive fracturing, and to corrosion, pitting and grooving.



A test set-up in the Westinghouse Research Laboratories for investigating the qualities of spring materials

"It is my prediction that with the rapid improvement being made in steel casting production facilities, we may soon be able to use high-pressure integral cast steel boiler shells, and also integral cast wheel centers and axles, integral cast piston heads and piston rods, cast main rods and cast side rods, and similar units, substituting the cast construction for rolled and forged parts, the metal of which now originates in a cast ingot. By this change, much of the present excess weight,



The latest of American locomotives designed by J. H. Muhlfeld for the Delaware & Hudson railroad and built by the American Locomotive Company. One of the outstanding features is the poppet-type valves

forming, punching, shearing, riveting, welding, machining, fitting and fabrication, together with the delay and cost incident thereto, can be dispensed.

"With reference to the locomotive 'L. F. Loree,' Delaware & Hudson No. 1403, the boiler shell is made of Silico-Manganese steel, and the intermediate and rear header plates in contact with the fire are made of low-carbon nickel steel. The 30-in. diameter steam and the 20-in. diameter water drums are seamless pressed and drawn low-carbon nickel steel, having a tensile strength of about 80,000 lb. per sq.in., and a yield point of about 47,000 lb. per sq.in., with an elongation in 2 in. of about 32 per cent, and a reduction in area of about 60 per cent.

"The thickness requirements through the perforated portion of the drums for the application of the water tubes is about double that of the opposite unperforated portion. This difference in thickness was obtained by eccentric turning of the outside of the shells. The substitution of these four seamless steel drums at the firebox end of the boiler in place of the conventional riveter drums enabled the elimination of a total of 660 pieces and a reduction of 5,670 lb. in weight.

"With respect to the boiler tubes and the superheater fire flues, these are cold-drawn seamless tubing of nickel steel having a nickel content of about 0.25 per cent. The elastic limit of this material is 50,000 lb. per sq.in., the tubes having a minimum bursting pressure of 2,000 lb.

"We have also used Ascoloy plates to reduce weight, using it in place of refractory brick, which latter would not permit of making tight joints and would substantially increase the dead weight.

"Major forgings such as main driving axles and crankpins, main rods, side rods and piston rods, were made of quenched and tempered carbon-nickel steel produced by the open hearth furnace. The refinement of the grain in these forgings was produced by uniformly re-heating to the proper temperature and quenching, and finally by uniformly re-heating to the proper temperature for tempering or 'drawing' back, after which the forgings were allowed to cool uniformly. With this treatment, a minimum tensile strength of 100,000 lb. per sq.in., minimum yield point of 75,000 lb. per sq.in., minimum elongation of 25 per cent in 2 in., and a minimum reduction of area of 50 per cent was obtained. In the case of the reciprocating parts such as piston rods and the front end of the main rods, this material enables a substantial reduction in weight. Thereby, the influence of inertia on the main driving wheels, crankpins and piston rods, of which quite a number of failures occur, is reduced substantially.

"A large factor in locomotive design which contributes to decrease in weight, is the reduction in the number of parts. I have already referred to the number of parts eliminated through the use of seamless steam and water drums at the firebox end of the boiler. In addition, some 850 parts can be eliminated by casting the cylinders and frames in one piece of steel and eliminating the fabrication of the frames, cylinders, crossties and other connecting parts separately and then connecting them with bolts and nuts.

"Likewise, casting the tender frame in one integral piece of steel saves a large number of parts. This applies equally as well to freight cars, where the casting of the underframe and eight hoppers in one integral piece of steel weighing approximately 18,700 lb., eliminated 184 different parts and the use of 2,250 rivets for assembling the same.

"While the foregoing cannot be taken as a complete outline, I believe it will impress you with the many advantages of reducing the number of parts and the weight of steam locomotives by substituting for separately fabricated and assembled parts a design that permits integral cast construction. It also emphasizes the use of alloy steels for the purpose of increasing strength and reducing unproductive or otherwise undesirable weight."

High-Strength Shafts and Axles

Regarding shafts, A. C. Rasmussen, chief engineer of Insley Manufacturing Company, states that they use alloy steels almost entirely, except when necessary size for other reasons greatly reduces the working stresses. In order to obtain low production cost, such alloy shafting is bought from the mill fully heat-treated, hardened and drawn to a hardness just within the machinable limit. For S.A.E. 3140 this hardness ranges between 262 and 293 B.H.N.

Rear axles for automobiles, according to E. F. McPherson, metallurgist of the Hupp Motor Company, were formerly made of chrome-nickel steel. This material is still in quite general use, but in some applica-

tions is now being changed to chrome-molybdenum steel, largely on account of the easier machining qualities of the latter steel and the fact that it is capable of withstanding higher torque. W. C. Bulette, president and general manager of the Brandt-Warner Manufacturing Company, made a similar statement. This company specializes in the production of nickel-chromium steel automobile axle shafts for trucks and passenger cars, and propeller shafts of the same material for passenger cars. For bus shafts, where higher tensile strengths are required, this company uses a steel having the same composition as S.A.E. 3140 with the addition of 0.15 to 0.20 Mo. After heat-treatment the material has a tensile strength from 190,000 to 200,000 lb. per sq.in. Not only does the addition of molybdenum increase the machinability of the steel, but it also permits of a wider range in heat-treatment.

F. A. Firnhaber, chief engineer of the Landis Machine Company, states that chrome-vanadium steel has superseded carbon steel for round wire and flat springs because of the resulting higher factor of safety.

Materials Subjected to Impact

Closely allied with the strength and ductility of the material is the problem of providing resistance to impact. Two factors must be considered—one is the direct failure of the material by fracture, and the other is the prevention of damage to the surface of the material.

One interesting point emphasized by Dr. Brace, of the Westinghouse Research Laboratories, is that the impact strength of a material of a given chemical composition will vary over a wide range because of differences in grain structure, re-crystallization and other similar factors. As an example, one sample of a given material might have an impact strength of only approximately $\frac{1}{4}$ or $\frac{1}{5}$ of that of another sample because of differences in grain structure.

A group of aluminum-bronze permanent mold die-castings designed by Westinghouse engineers for electrical equipment and devices

One unusual problem involving impact confronted the Harrington & Richardson Arms Company. As explained by J. W. Harrington of that company, when revolvers are snapped without a cartridge in front of the firing pin, the front portion of the firing pin, which portion is only about $\frac{1}{2}$ in. long and $\frac{3}{16}$ in. in diameter, will pull away from the wider portion of the pin and finally break off. A great number of alloy steels with various hardening and tempering treatments were tried. Finally beryllium copper was adopted, which has given better results than any other material that had been used.

Concerning the materials that have been used or recently adopted for construction equipment, A. C. Rasmussen, chief engineer of Insley Manufacturing Company, states that cast iron is now almost entirely replaced by cast steel except for the use of cast iron as filler blocks. Where loads are not excessive, but where shock is encountered, malleable iron is used. In addition to its dependability to withstand shock, it has the advantage that the castings come so true that machine work is reduced to a minimum. The ease of machining this material is another point in its favor.

Cams Subjected to Impact and Wear

National Acme Company formerly used cast iron and semi-steel for the cams in its automatic screw machines. A. E. Drissner, vice-president in charge of engineering of that company, states that on account of the employment of heavy-duty cutting materials now in use the pressure of the cam follower rollers on the cam surface has increased approximately 600 per cent. For this reason it was necessary to increase the surface area of the cams somewhat and to use forged or cast high-carbon steels for the cams which are hardened by heat-treatment.

This same company also manufactures the Chronolog, a device for recording duration and causes of idle machine time. The index gears of this device were formerly made of S.A.E. 2315 steel (3.50 Ni), but the material was not capable of properly resisting the shocks and wear incident to the operation of the machine. These gears are now made of a steel equivalent to S.A.E. 6140, containing 0.95 Cr and 0.17 Va.

One of the most remarkable applications of zinc die-castings for wear and impact resistance is reported by Mr. Lawson. Zinc die-castings are used for the cam disks that effect reverse plaiting on their circular knitting machines. These disks have a succession of teeth, closely spaced, which teeth actuate plungers that control the pattern being knitted. A circular groove, V-shaped, at the root of the teeth makes it an easy matter to break out the teeth with a pair of pliers. The remaining teeth control the pattern that is knitted.

In this instance, the advantages of the use of the die-cast disks are that the space occupied is approximately one-half of that occupied by the steel cams formerly used, the steel cams had to be machined for each different pattern, and with the die-cast disks it is an extremely simple matter to change the pattern.

JULY NUMBER

T. Holland Nelson, noted consulting metallurgist, classifies the chrome and chrome-nickel steels with reference to the effect of variation of nickel, chromium and carbon content on the workability, physical properties, heat-treatments required and corrosion-resistance characteristics. Not a metallurgical dissertation, but a simple exposition of facts

The severity of the service to which these cam disks are subjected can be judged by the fact that the machine makes 200 r.p.m. The plungers that are actuated by the cam disks receive 120 impacts per revolution, making a total of 24,000 impacts per minute upon the plungers. These plungers are made of high-speed steel, this being about the only material that was found to give the necessary surface hardening to resist wear and at the same time did not warp in heat-treatment. For the plungers, Hemphill Company uses Rex AA steel, which is bought in flat strips 0.045 in. thick and then ground. This material is used for all thin cams up to approximately $\frac{1}{16}$ in. thick.

For the thicker cams subjected to hammer blow and wear, it is of utmost importance that the surface of the cam shall not dent. Both oil-hardening and water-hardening tool steels are used for this purpose. Case-hardened cold rolled steel is used for cams that are subjected only to a slight amount of wear.

Alloy Steels for Machine Tools

For machine tools, F. A. Firnhaber, chief engineer, Landis Machine Company, indicates that there has been considerable improvement through the use of alloy steels and non-ferrous alloys. Referring specifically to the product of his company, where formerly cast iron was used for barrel and face cams, 0.12 to 0.22 carbon steel castings are now used. The rollers are carburized to about $\frac{3}{64}$ in. deep and then hardened to give durability.

Tooth clutches, small gears, racks and safety clutch plungers and all other parts subjected to both shock and wear and where high fatigue properties are required are made of a manganese steel whose composition is 2.00 C, 0.75 Mn, and 0.50 Si. Two primary reasons for the use of this particular material are that it does not change its shape in heat-treating and has a high tensile strength.

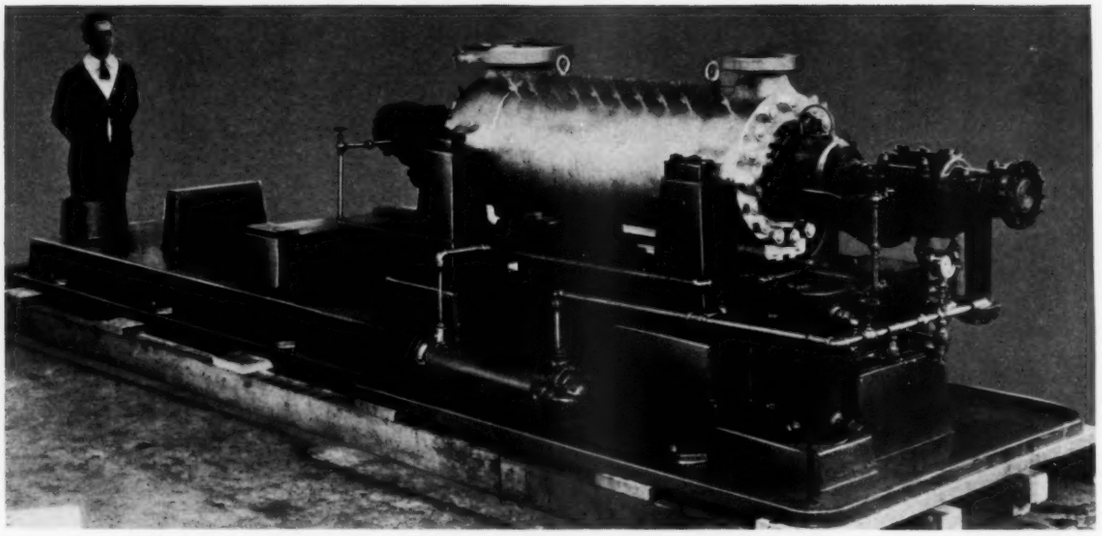
Although S.A.E. 2315 steel (3.50 Ni) has proved satisfactory in many installations, this material is now largely superseded by heat-treated gears made of S.A.E. 3145 steel (0.60 Cr, 1.25 Ni). Pawls on which heavy pressures are exerted are made of the same material and heat-treated. Chrome-molybdenum heat-treated steel is used by the Landis Machine Company for locating and guiding bushings requiring resistance to severe abrasion. Pins or studs for cam rollers are of hardened and ground S.A.E. 3140 steel. If softer grades of steel are used flats are worn by the severe pressures to which these rollers are subjected.

Metals for Service Under High Temperatures

TUBES for stills and condensers such as used in the chemical industries are subjected to both high pressures and temperatures. Tubes in such service are frequently observed to be heated to a bright red heat when viewed in the dark, this representing a temperature of approximately 1,000 to 1,100 deg. F. At the same time, oil or other liquid inside the tubes may be under a pressure of as much as 1,500 to 1,600 lb. per sq.in., thereby putting the materials of the tubes under a high stress.

One of the most desirable features in such tubes is to have thin walls. This is not only to increase the rate of heat transfer, but because thick tubes will have a high temperature gradient through the tube wall. The difference between the temperatures on the outer and inner surfaces of the tube makes a correspondingly large difference in thermal expansion. The result will be extremely high stresses imposed by this difference in expansion. Under some conditions, beyond certain thicknesses the thermal expansion stresses become greater than those created by the pressure inside the tubes.

When discussing the problem of materials for such tubes, George Eaton, chief engineer of research of Spang-Chalfant & Company stated that in former years the tubes were plain 10 to 25 carbon steel, of which material many are still being made. Such tubes are apparently sufficiently strong, but they corrode rapidly under certain conditions. Most of the tubes in use today are of 4 to 6 per cent chromium. These straight chromium tubes are considered as "standard" and take the base price, a fact which undoubtedly largely influences their general use. In some instances, 1.0 per cent tungsten, or 0.50 per cent molybdenum is added. It is difficult to determine which of these added elements is the better, both users of tungsten tubes and users of



A ten-stage Ingersoll-Rand oil pump embodying materials for corrosion and erosion resistance at high temperatures

molybdenum tubes claiming advantages. It is generally claimed that molybdenum reduces temper embrittlement. It appears as if the addition of 1 per cent molybdenum is finding favor because of its higher creep resistance.

According to engineers of the Babcock & Wilcox Tube Company, the most general purpose alloy for elevated temperature use involving scale resistance, corrosion resistance and creep is 18 per cent Cr—8 per cent Ni. This material combines the above properties with good room temperature properties, weldability and no alteration of physical properties with continued heating at elevated temperatures. Where no pressure or stress is involved, tubes of this material can be used up to temperature of 1,700 deg. F. When stress and corrosion is involved, such as in tubes under internal pressure, this material is not recommended for service above 1,300 deg. F.

While 18 per cent Cr steel is not as resistant as 18-8 Cr-Ni to above conditions, it may be used for a number of services involving elevated temperature corrosion where the temperatures involved do not allow for continued heating in the range 1,000 deg.-600 deg. F. or slow cooling from a higher temperature through this range. Under the above conditions 18 per cent Cr steel has a tendency to become exceptionally brittle at room temperature. In addition, the physical properties of this steel at room temperature are not as good as those of the 18-8 Cr-Ni steel and the material cannot be welded readily and its creep value is considerably less.

For exceptionally high temperatures up to 1,900 deg. F., a 25 per cent Cr—20 per cent Ni steel is suggested. This alloy has good creep properties and excellent corrosion resistance.

For service at high temperatures where scale resistance is necessary, but no great stresses are involved, an alloy of 28 per cent Cr is suggested. This material has poor room temperature physical properties and is not easily worked.

An alloy containing 4-6 per cent Cr and 0.50 per cent molybdenum has been found to be economically advantageous for use under certain conditions where a reasonable amount of corrosion and stress at elevated temperatures is encountered. While this alloy does not have the corrosion resistance and creep strength of KA2S, which are required in only extreme cases, its admirable qualities, low cost and long life have made it the biggest tonnage alloy in cracking still tubes.

Interviews with engineers of the Foster-Wheeler Corporation revealed that this company uses S.A.E 6120 chrome-vanadium steel for the small-bore tubing in high-temperature reheaters, the material being required not only to withstand high temperatures but also corrosion and oxidation.

In high-temperature and high-pressure vessels having bolted heads and flanges, Foster-Wheeler usually specifies S.A.E. 3140 and S.A.E. 4140 (nickel-chromium and molybdenum steels respectively) heat-treated under Class C specifications of the S.A.E. Bolts and fastenings made up according to these specifications have been most successful under severe operating conditions encountered in high-pressure high-temperature heaters, reheaters and superheaters.

The most severe temperature conditions encountered by Foster-Wheeler in metallic apparatus is in supports for roof tubes of high-temperature oil stills. The tubes of the stills are exposed to the radiant heat of the furnace and must withstand pressures of 1,000 lb. per sq.in., and must heat corrosive oils to temperatures up to 950 deg. For these conditions a ferrous alloy containing 4 to 6 per cent chrome, ½ of 1 per cent molybdenum, and less than 0.2 per cent carbon has been found satisfactory.

Creep or Plastic Flow

Particularly where metals are subjected to stress at high temperatures, it is necessary to consider the factor of creep as it is commonly called. But creep may take place at ordinary temperatures. The Crompton & Knowles Loom Works discovered that their customers were required to tighten repeatedly the bolts on their looms after the machines had been put into service. An investigation disclosed that the high tensile stresses in the bolts caused them to stretch gradually, thereby

loosening the nuts. As explained by Albert Palmer, assistant to the vice-president in charge of development work of this company, in order to increase the service value of their machines to the customers by eliminating the expense incidental to repeatedly tightening the nuts, S.A.E. 3135 alloy steel heat-treated bolts (1.25 Ni, 0.60 Cr, 0.35C), were specified in place of the low-carbon steel bolts formerly used.

A similar situation was disclosed by A. E. Drissner, vice-president in charge of engineering of the National Acme Company of Cleveland. The holding screws and bolts formerly used in their screw machines were of machine steel, case- or cyanide-hardened. Under present loads, bolts and screws of this material begin to loosen in from 2 to 3 hours. Therefore, this company now uses S.A.E. 3140 alloy steel (1.25 Ni, 0.60 Cr, 0.40 C), or S.A.E. 6140 (0.95 Cr, 0.16 Va, 0.40 C) for all bolts and screws.

Chrysler Motors Corporation has an unusual manner of handling heat-treated steel bolts. Formerly, all sizes of bolts and studs were made of 0.27 to 0.37 carbon steel. This necessitated a different heat-treatment for each size. In order to overcome this handicap, steel of different carbon content is used for the different diameters of bolts and studs. For the smaller sizes of bolts, the carbon content runs up to 0.30, for the medium size bolts up to 0.32, and for the larger diameter bolts the carbon content has a maximum of 0.35. All bolts are then given the same heat-treatment.

The connecting rod bolts for the refrigeration compressors of the Frick Company are of high carbon steel for ordinary service. To avoid the possibility of creep, chrome-vanadium steel is used for highly stressed bolts.

On steam turbines, bolts become heated up to a temperature in the neighborhood of 600 deg. F. On account of space requirements it is necessary to use bolts of minimum diameter, some being stressed up to 50,000 lb. per sq.in. It is therefore necessary to use a material that will have an extremely low creep rate. For this service, Westinghouse uses 11½ to 12½ per cent chrome steel, containing less than 0.10 carbon and 0.6 nickel. This material has a creep rate about one-half that of plain carbon steel.

To illustrate the tremendous creep that takes place in ordinary bolts, in the experiences of one engineer an initial load of 60,000 lb., was reduced to approximately 17,000 lb. after six months in service.

Low creep rate is also an important factor in turbine spindles where temperatures are high. For this service, a heat-treated alloy steel containing 2.5 Ni, 0.60 Cr, and 0.25 Mo, and with carbon content 0.4, is used.

Bolts and studs of chrome-vanadium steel, heat-treated to give 105,000 lb. per sq.in. elastic limit, 125,000 lb. per sq.in. ultimate strength with 17½ per cent elongation and 55 per cent reduction in area, are used on the high-speed diesel engines of the Baldwin-Southwark Corporation. This material is used on account of its high fatigue values and resistance to creep.

When Weight Is an Important Factor

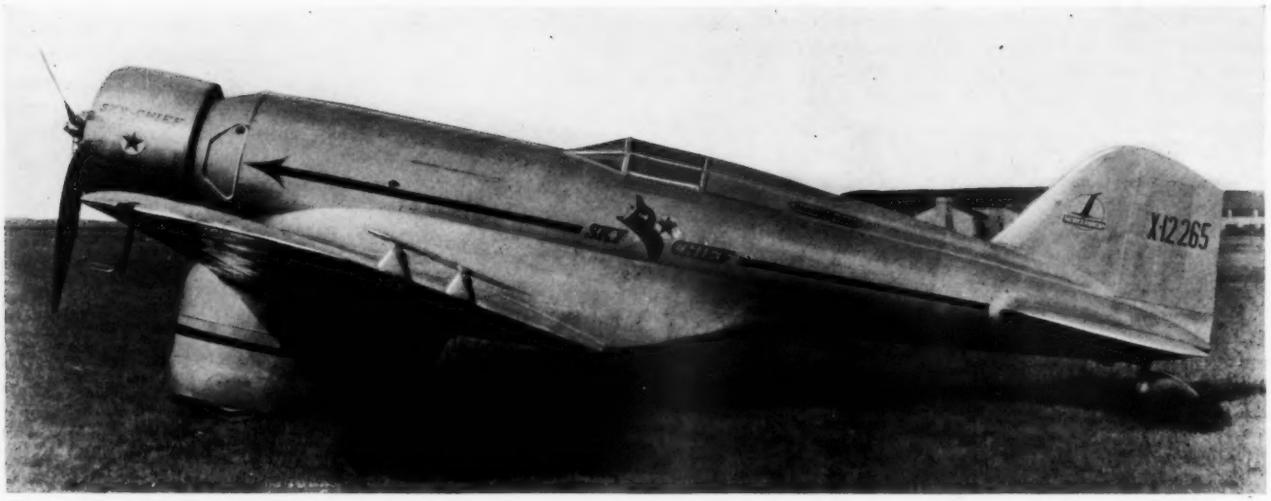
MINIMUM weight may be desired for one of two reasons. The nature of the part or product may be such that lightness is in itself required or desired. This is the situation in aeronautical design and to a more or less degree is true for all transportation vehicles and equipment and parts that must be portable. The other primary reason for reducing the weights of parts is to reduce the magnitude of the inertia forces, as in pistons, oscillating wheels and similar units.

In considering the problem of weight reduction it is not sufficient to give attention to only those materials of light unit weight. During the past year there have been two remarkable developments in light equipment for railroad service, namely, self-propelled rail cars. Each of these developments represents an entirely different method of attacking and solving the problem of procuring light weight and strength. In one of these designs the engineer resorted to aluminum alloys, in the other to corrosion-resisting steels.

Light-Weight Rail Cars

In the Autotram, built by the Clark Equipment Company, aluminum alloys were used for the entire body of the car, and underframe. The design of the underframe follows along the lines of the typical railroad construction, using a box girder-type center sill which is built up of 17 ST aluminum plates and angles. Side sills are 6-in.x⅜-in. bar plus a special extruded Z-section. Floor beams are 4-in. 17 ST rolled channels, and the cast fittings are 195-T4 alloy castings. To minimize

Pouring a heat of stainless steel from a coreless induction electric furnace at the Barberton Works of the Babcock & Wilcox Company. Castings of this steel are used for chemical and oil refinery equipment



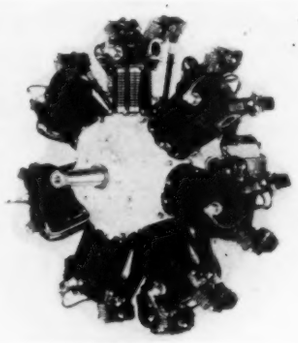
All-metal monocoque construction high-speed plane built by the Northrop Corporation, equipped with Wright whirlwind, 14 cylinder, double-row radial engine

air resistance a fairing of 0.051 in. 3 SH aluminum sheet was placed under the floor beams. Body side posts, letterboard angle, door posts and window frames are all made of extruded dural sections, as are the roof carlines and all other structural members. Roof sheets, floor sheets and interior paneling are all aluminum sheets.

The other outstanding rail car that was produced last year is the "Budd-Micheline" built by the E. G. Budd Manufacturing Company. An entirely different engineering procedure was adopted for development of this car. Perhaps the biggest factor that adds weight to railroad equipment is the necessity of providing additional thickness to sheets and structural members in order to compensate for the loss of thickness on account of corrosion. Using corrosion-resisting steel, this extra thickness is not required.

One of the difficulties encountered in the use of corrosion-resisting steels was the problem of connecting the members. On account of weight saving it was extremely desirable to use welding. But one of the effects of welding on the chrome-nickel steels is that the chromium is precipitated, thereby permitting corrosion of the metal at the weld. To overcome this difficulty, the E. G. Budd Manufacturing Company developed the shot-welding process. In this process, which is a form of spot welding, an extremely high current for short duration of time is used. On account of the short-time element, there is no opportunity for the precipitation of the chromium with the result that the "shot welds" do not corrode.

The Budd-Micheline car departs from "standard" railroad construction and follows more along the lines of automotive practice. All of the structural members, both in the underframe and car body, are made of chrome-nickel steel having a tensile strength of about 150,000 lb. per sq.in. Panels are approximately 0.015 in. thick and embossed to procure greater rigidity. Sheathing is the same thickness. All of the structural members are built up of sheets formed and shot-welded. All load-carrying members are built up of chrome-nickel steel, but the roof is aluminum sheet.



Using high-strength and light materials, designers of airplane engines have achieved amazing results. This Warner "Scarab" weighs 2.15 lb. per hp. With superchargers, a weight as low as 1.2 lb. per hp. has been obtained

For instruments manufactured by the Pioneer Instrument Company, we are informed they use aluminum for the instrument cases, the aluminum being given the anodic treatment before painting. In some instances, for light-weight cases they now use a newly developed bakelite, strong and tough, and lighter than painted aluminum. This material absorbs up to 3 per cent moisture, and is used only for the external case, a brass case being fitted inside. Wherever aluminum is used, no brass parts are allowed to come in contact.

Aeronautical Design

In no other field is the question of weight of such great importance as in the design of airplanes and airships. Considering the practice of The Northrop Corporation, W. K. Jay, vice-president and general manager of that company, briefly outlines their use of nonferrous metals for high strength and light weight as follows:

"Northrop airplanes are all-metal and of the monocoque or semi-monocoque type, in which all loads are taken through the skin and its stiffeners. The major problem of structural design then becomes one of carrying bending and compression loads through a thin skin. Inasmuch as the strength of flat sheets in compression varies as the square root of the yield point and the modulus of elasticity and as the square of the

thickness, the lighter alloys are usually superior to steel for the type of structure we use.

"While there are some high-strength steels of equivalent strength-weight ratio in tension, aluminum and magnesium alloys are used almost exclusively in the Northrop structures, in spite of the fact that steel would be better from a corrosion standpoint.

"Some saving in fabrication cost is also experienced because of the ease of forming even the hardest of nonferrous alloys as compared to the high-tensile steels. Probably 80 per cent of the alloy structure is fabricated in the hard state without annealing or heat-treatment.

"The major parts of the fuselage, wings and empennage, viz: skin or covering, stiffeners, bulkheads or shear members, etc., are formed from 24 SRT aluminum alloy. Most of the fittings, however, are of cast Dowmetal A. This latter material is a magnesium alloy whose chemical composition is approximately 91.8 per cent magnesium, 8.0 per cent aluminum, and 0.2 per cent manganese. Its physical properties are good and consistent, the material is free of foreign matter and blowholes, and its machining characteristics are excellent.

"At the present time the aluminum alloys and, even to a much greater extent, the magnesium alloys, are subject to rapid corrosion around salt water. This trouble must be overcome before either of these alloys can achieve an extensive volume in marine and other uses."

In summarizing the practice of the Warner Aircraft Corporation, C. J. Lane, assistant chief engineer of that company, states:

"Dowmetal is used for airplane wheel castings, covers, brakes or backing plates and all parts where extremely light weight without high-tensile strength is required.

"Aluminum is used by us extensively in the cast form and also in the extruded form. In the cast form we use it for crankcases, cylinder heads, induction housings and similar parts. In the extruded form we use it for tubing in the manufacture of shock struts.

"We use the high-strength alloy steels to resist stresses such as imposed by impact, vibration and fatigue. Of particular note is the chrome-molybdenum steel alloy for shock struts, cylinder barrels and parts requiring similar properties. The high-nickel steels are used extensively for such parts as crankshafts and connecting rods."

Light Weight for Decreasing Inertia

There are numerous applications wherein aluminum or aluminum alloys are used to decrease the weight of reciprocating or oscillating masses. Aluminum pistons for automobile engines are one of the best known applications. The high-speed diesel engines of the Baldwin-Southwark Corporation have aluminum pistons. In the circular knitting machine of the Standard-Trump Company, the revolving bobbin rack is made of aluminum primarily to secure light weight and reduce the inertia forces. The bobbin cages on the knitting machines manufactured by the Hemphill Company are also made of aluminum. Robert H. Lawson, chief engineer of the Hemphill Company, explained that not only is lightness desired because the cage is held on a bracket and extends quite a distance from the frame of the machine, but the reduced torque required for starting correspondingly diminishes the load on the bronze driving gears.

One unusual reason for the adoption of an extremely light metal was reported by L. R. Tufts, chief engineer of the Cleveland Folding Machine Company. The cast-iron cross carrier on their folding machine weighed approximately 75 lb. In the operation of this machine it is necessary for the operator to lift out the carrier. On account of its weight, it was obvious that no girl operator could do so. An extremely light roll would have been a valuable feature, for which reason it was decided to make it of cast Dowmetal. The weight of the roll was reduced to less than 20 lb., making it easy for a girl operator to lift it from the machine bed as desired.

In this same machine the deflector bar is made of extruded aluminum. Also the guide finger assembly, which was formerly a brass bracket with steel guide fingers riveted to it, is now made in one piece of extruded aluminum. In spite of the high material costs, the cost of a finished part is approximately one-half that of the previous design

The Field of Die-Castings

With reference to the general experience of manufacturing companies in the adoption of die-castings, M. F. Lowry, of the Engineering Department of the Hoover Company, states that in their experience there is usually a lower cost for metals when using die-castings because of the reduced sections, which also reduces the weight of the part and the finished product. In addition to this, the fact that the part can be cast closely to finish dimensions very materially reduces the machining and other finishing operations. With a smooth surface, the buffing and polishing costs are reduced.

Not only is the finished product lightened considerably, but because of the closer graining on the surface there is usually an improvement in appearance and, because of the better distribution of metal, a slight increase in strength.

According to H. H. Ashdown, metallurgist, Westinghouse Electric & Manufacturing Company, that company makes considerable use of zinc die-castings for small and medium-size parts where corrosion resistance and appearance are a factor. Ordinarily, zinc disintegrates in steam or warm, moist atmosphere, but special alloys developed are highly resistant to such disintegration and also have higher strength and ductility and better metal flow. These properties are largely a function of the manganese copper content of the zinc.

Die-cast pushbutton covers have replaced cast-iron covers because of the better appearance of the zinc die-castings and because of the fact that the absence of machining operations makes the die-cast cover more economical. All of the holes are cored, even those for the screws for fastening the cover.

Both Westinghouse and General Electric fractional horsepower motors, such as fan motors, use zinc die-cast end frames without bearing bushings. That is, the armature shaft runs directly on the zinc die-casting. Marine and railway motors use aluminum cast end frames.

Dashpots for relays and time-delay devices are usually zinc die-castings because of the elimination of machining, neat appearance and their resistance to rust. These parts were formerly made of cast iron and machined.

Typical Anti-Friction

Second of a series of design work sheets showing

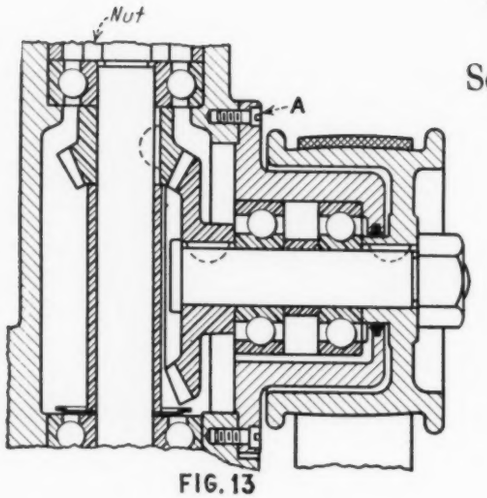


FIG. 13

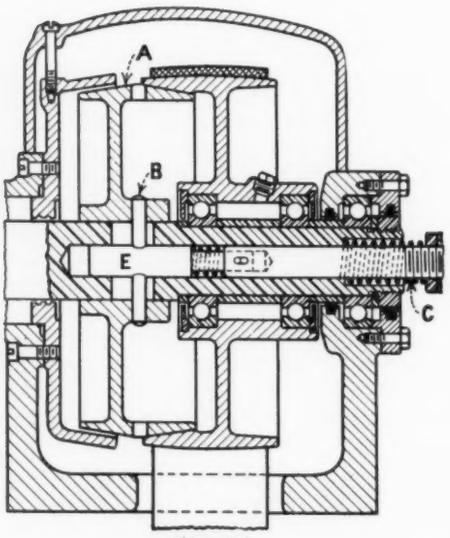


FIG. 14

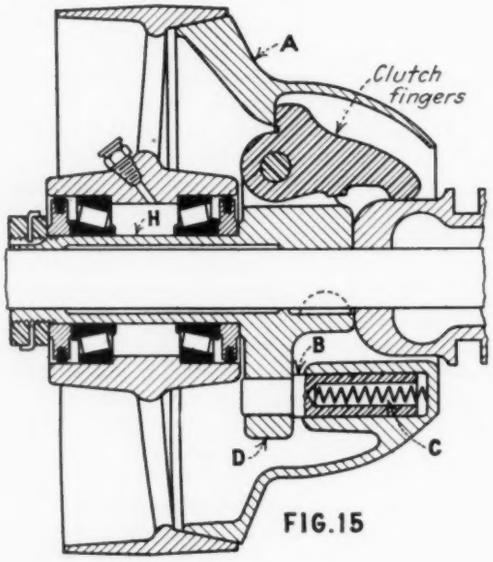


FIG. 15

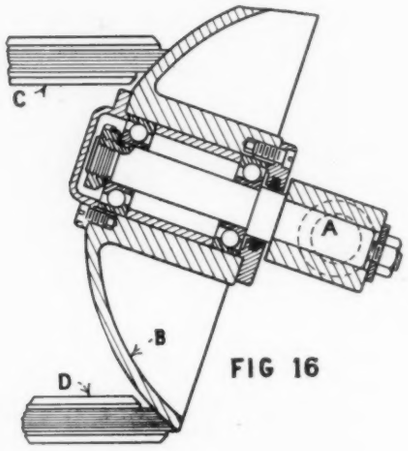


FIG 16

ADAM FREDERICKS

Fig. 13—Bevel gear and pulley mounting. The left-hand bearing takes the bulk of the thrust load from the bevel gear, both bearings being mounted in the detachable housing *A*. One nut clamps pulley, gear and bearing.

Fig. 14—Pulley, mounted directly on the spindle, is engaged by cone clutch *A* driven by pin *B* pressed into a central two-piece rod *E*. Pushing rod *C* to left disengages the clutch.

Fig. 15—Cone clutch *A* is mounted slidably on three studs *B*, springs *C* keeping the clutch out of engagement. Hub *H* integral with spider *D* accommodates two tapered roller bearings clamped in place with felt seal collars by locknuts.

Fig. 16—Pivoting around center *A*, the spherical intermediate wheel *B* is driven by *C* and drives *D*. Opposed combined radial and thrust bearings are used, the outer races separated by a tube forced into the hole.

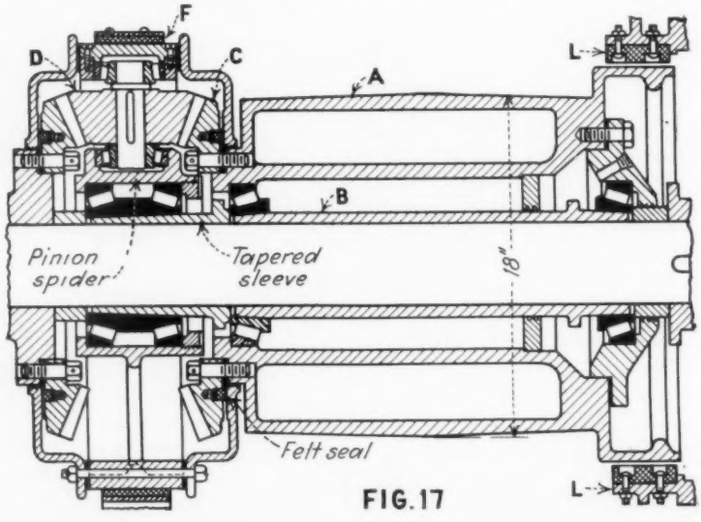


FIG. 17

Bearing Mountings—II

representative mountings for wheels and pulleys

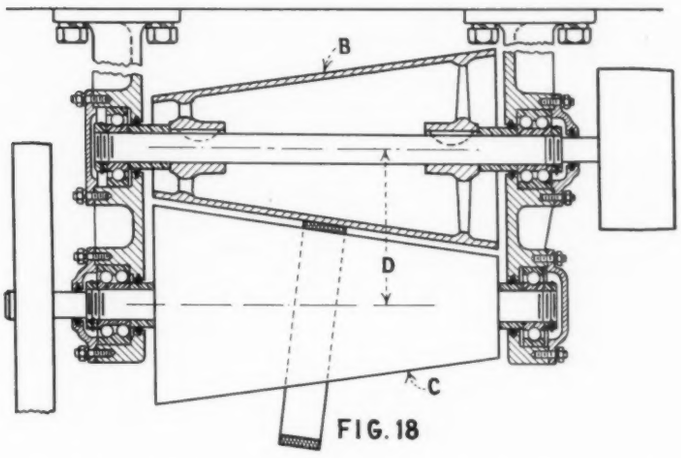


FIG. 18

Fig. 17—Pulley *A* is mounted on two tapered roller bearings pressed on tapered ends of the split sleeve *B*. Bevel gear *C* meshes with three pinions *D* and is screwed to the pulley. *F* is a brake band with molded lining, and is clamped for reversing drive. Direct drive is through clutch shoes *L-L*.

Fig. 18—Endless belt transmits the power from cone *B* to *C*, belt being shifted for different speed ratios by a fork, not shown. This construction can be varied by increasing center distance *D* to 18 to 24 in., and using a crossed belt.

Fig. 19—Conveyor pulley mounted on stationary shaft. The pulley revolves about the inner cones of the tapered roller bearings.

Fig. 20—The bearing assembly is fully self-contained in a sleeve. Labyrinth seals *A-A* and helical grooves *B-B*, cut in a direction opposite to rotation, retain the grease.

Fig. 21—Fixed shaft is held in the frame by retaining keys *A-A*, each sheave rotating on one centrally located double-row ball bearing. Grease reaches the bearings through slots *B-B*.

Fig. 22—Bearings are mounted on sleeve *B* having split taper ends to accommodate clamping nuts *C-C*. Bearing pushes against shoulder *A-A* in hub of pulley.

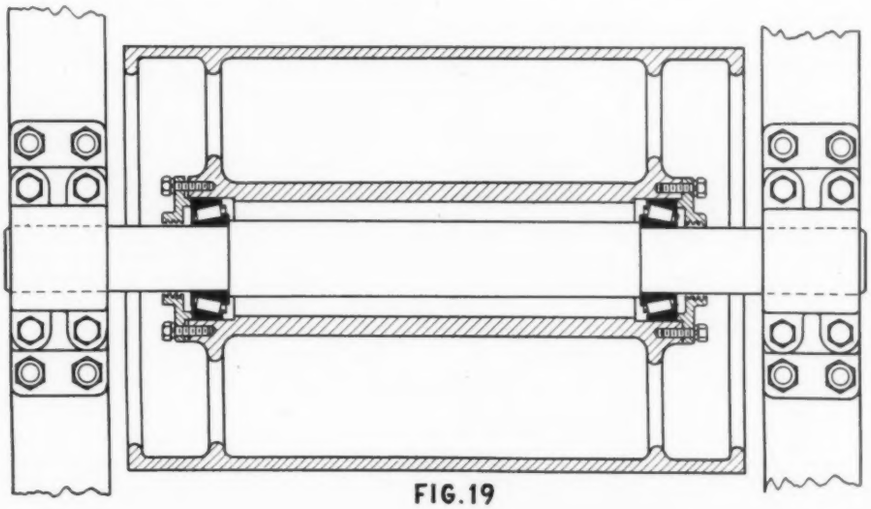


FIG. 19

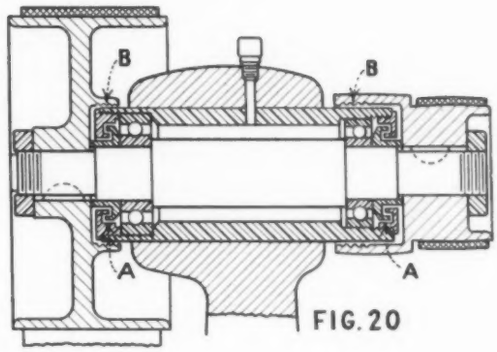


FIG. 20

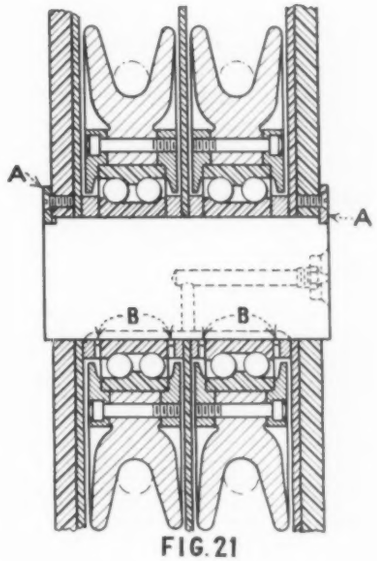


FIG. 21

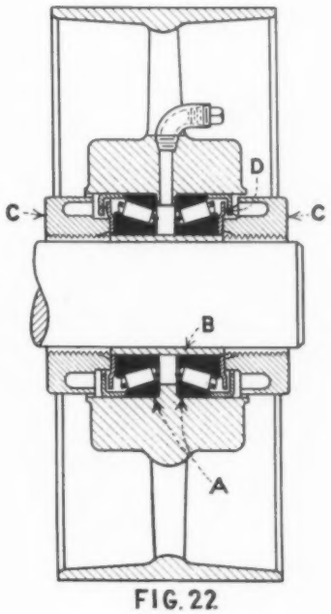


FIG. 22

PRODUCT DEVELOPMENTS

Automobile transmission with automatic shift—Brakes and safety devices on a knitting machine—Air steering for buses and trucks—Two room coolers—A mechanical lampbase—Axle generator geared drive—Gyro airplane pilot—Built-in flow switch

▼ ▼ ▼

▸ Reo Self-Shifting Transmission

After two years of development work, the self-shifting transmission designed by H. T. Thomas, chief engineer of the Reo Motor Car Company, has reached the announcement stage. It is now standard on the Reo Royale model. Essentially, the new transmission, which eliminates free wheeling, of course, offers four forward speeds and a reverse. A selector located on the instrument panel gives the driver the choice of two forward speeds and the reverse. Each of the forward speeds is stepped up when the self-shifter operates, at about 15 m.p.h. car speed.

For all ordinary driving the selector is pushed forward after the clutch is disengaged. This action slides gear *V*, Fig. 1, on the spline shaft over main drive gear *X*, at the same time moving the countershaft gear forward to clear *V* in its new position. The drive is thus direct to gear *P*, at the center of the automatic unit, Figs. 1 and 2. This gear meshes with internal teeth in gear *R*, the external teeth on *R* meshing with internal teeth on gear *Q*, which is directly connected with the propeller shaft. All normal starts are made through this internal gear train.

At a car speed of about 14 m.p.h. the eight governor weights *K*, which pivot at the forward end, swing outward and engage and lock the multiple disks of clutch *F*, thus causing the automatic unit to rotate with the spline shaft since the inner and outer drums are locked by the clutch. As car speed drops below 10 m.p.h. the governor weights retract and the clutch disks release, drive then being through the internal train as at first.

If the selector is moved straight back, countershaft gear *W* slides back, the forward section meshing with gear *X* and the rear section with gear *V*, thus providing a double reduction, external and internal, for slow starting under adverse conditions. At a car speed of about 15 m.p.h. the automatic unit goes into direct and the car proceeds on that gear until the selector is moved forward to disengage countershaft gear *W*.

For backing, the selector is turned 45 deg. clockwise in neutral and then moved back. This slides gear *V* and countershaft gear *W* back, and engages a reverse idler which reverses the direction of the spline shaft. Final drive is through the internal train.

▸ Brakes and Shock Absorbers for Knitting Machines

Much higher operating speeds demanded of full-fashioned hosiery knitting machines have led to the

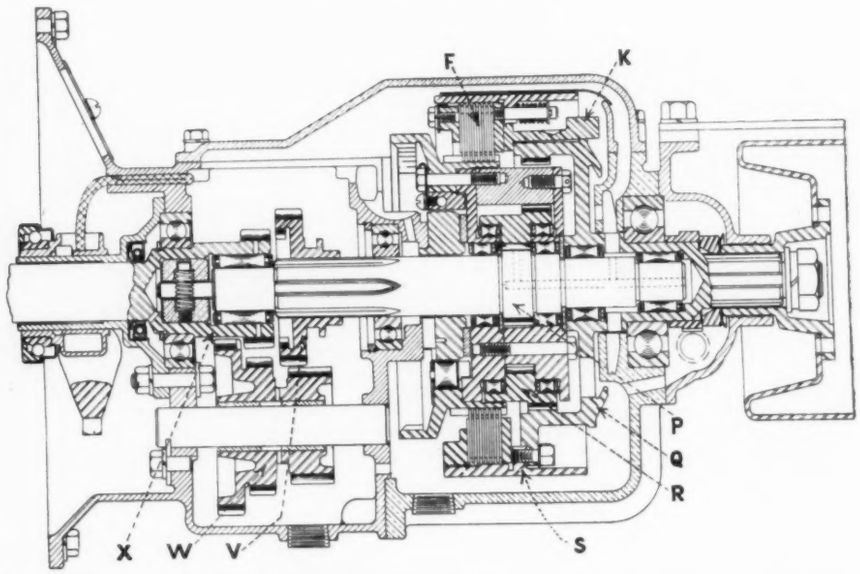
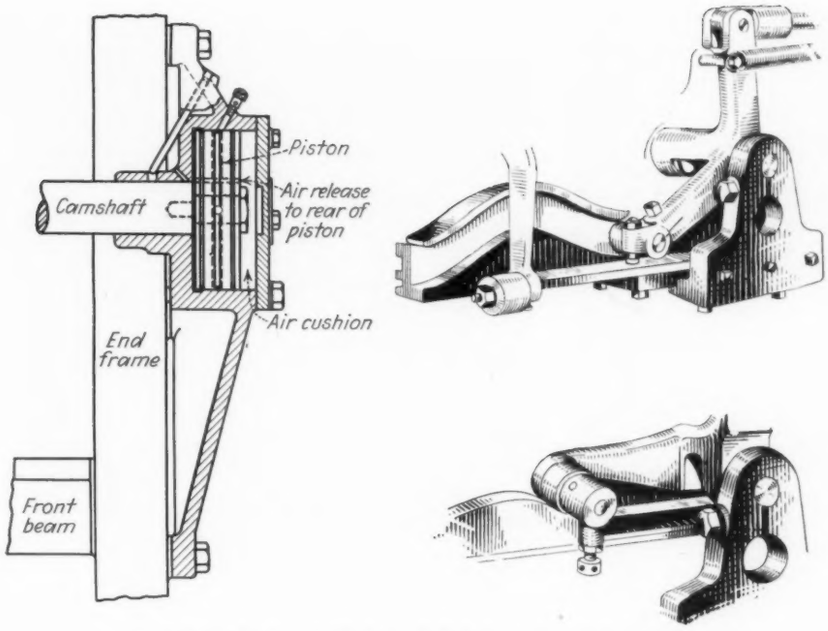


Fig. 1—Longitudinal section of Reo self-shifting transmission
Fig. 2—Transverse section through automatic unit



Air-cushion brake applied to full-fashioned knitting machine camshaft. Grooved-cam positive shock absorber that insures smooth operation of main carrier rod

development of safety devices for their machines by Textile Machine Works. Among these improvements are balancing cams to equalize torque and minimize speed variation of the camshaft, safety release for narrowing lift shaft to prevent damage when the operator lowers this shaft into position, a centrifugal type of safety stop for the take-up attachment, safety drive mechanism on the handwheel shaft, and the air-cushion brake for the camshaft and the positive shock absorber to eliminate shock and rebound from the main shaft, illustrated above.

The camshaft of a full-fashioned knitting machine must be shifted quickly, and with minimum shock. To reduce shocks the piston illustrated is fixed to the camshaft end. Surrounding it is an air-tight housing. Each time the shaft is shifted air is compressed between piston and housing, and cushions the shock. The air escapes slowly through a hole in the piston to the space on the opposite side to form a cushion when the shaft is returned to its original position.

To insure smooth action of the main carrier rod at any speed the grooved cam sketched above has been substituted for the old type also shown. The tendency of the old roller to jump away from the cam when speed increased is corrected by the restraint of the groove.

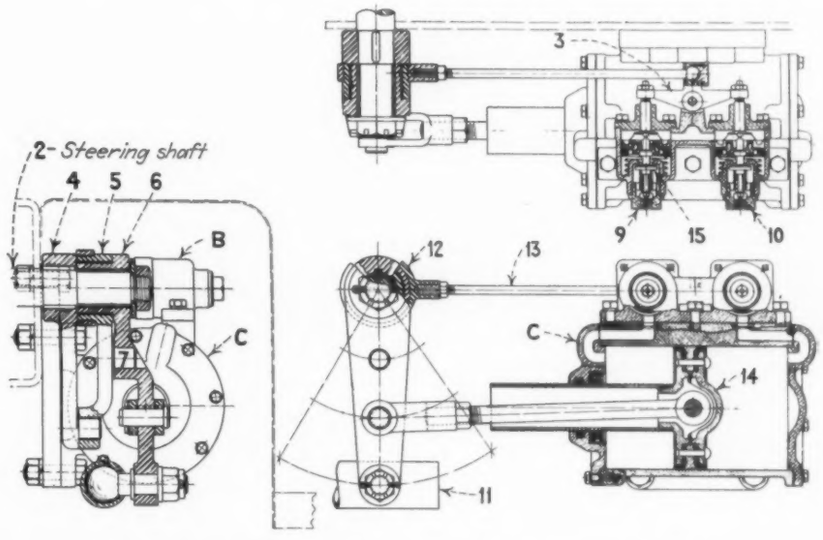
▸ Air Steering

Auxiliary pneumatic equipment to facilitate steering of motor trucks, buses and heavy passenger cars has been developed by S. Johnson, Jr., chief engineer, Bendix-Westinghouse Automotive Air Brake Company. It is applicable, of course, only to vehicles equipped with air compressors.

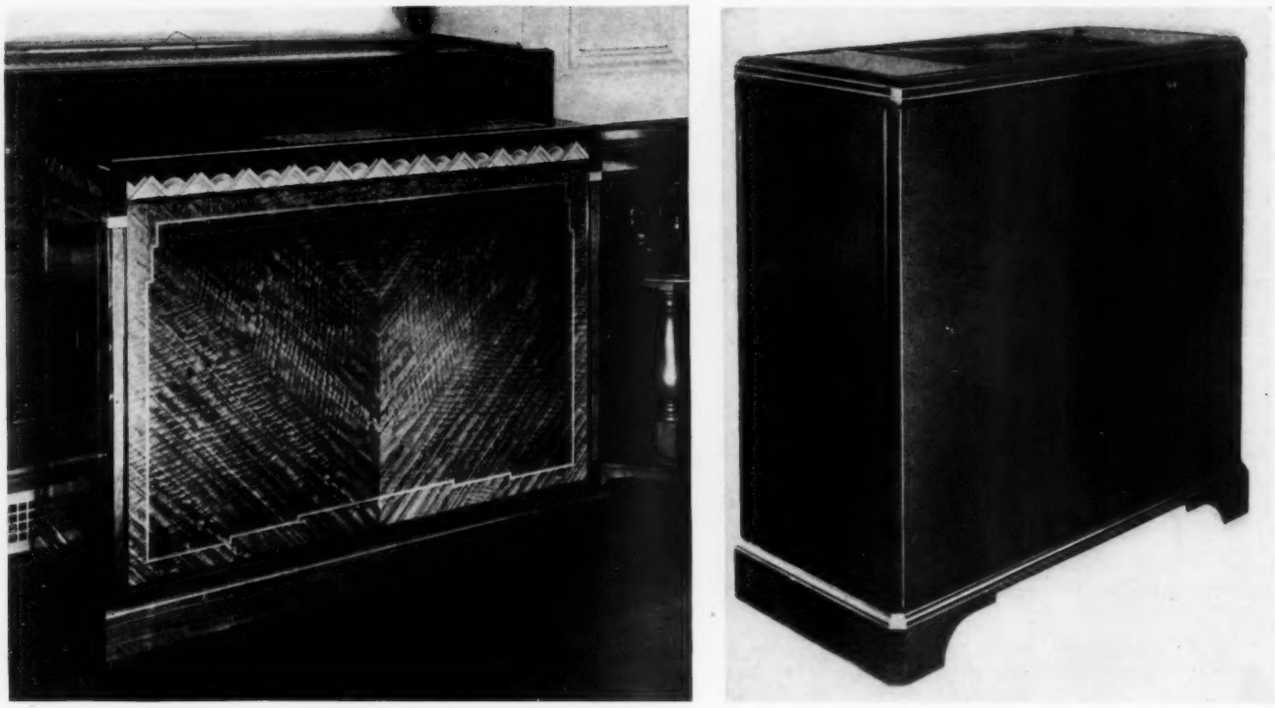
As illustrated below, the device consists of a double-acting piston and cylinder *C*, control valves *B*, and the combination of levers mounted on the steering rod. Air pressure delivered to the cylinder varies directly as the force applied to the valve piston plunger through the rocker arm *3* by the control rod *13*. Valves are so adjusted that air can be exhausted from both sides of the piston simultaneously, but can be admitted to only one side at a time.

Control lever *4* is fixed directly to the steering shaft *2*. Intermediate lever *5* is fulcrumed at the pitman arm *6* through pin *7*. Its lower end is connected to the control lever through pin *8*, while its upper end is bored slightly larger than the hub of the pitman arm so that it can move freely and actuate control rod *13*. Drag rod *11* is connected at the end of the pitman arm, and brake cylinder *C* midway between the end and pin *7*. Yoke *12* is mounted on *5* to keep control rod *13* in line with the steering gear camshaft.

If the steering wheel is moved for a right turn, control lever *4* moves to the right. As there is always a resistance to the turning of the wheels, *4* will move upper end of *5* to the left, and thus cause control rod *13* to put pressure on left hand control valve plunger through rocker arm *3*. The air pressure admitted to the cylinder moves the plunger and with it the drag rod *11*, thus accomplishing the desired object. Air pressure continues as long as the wheel is being turned. Thereafter the piston moves until the upper end of *5* has taken a position that shuts



Bendix-Westinghouse air steering control for automotive vehicles



DeLaVergne (left) and General Electric cabinet model room coolers

off the valve. The action of the combination is such as to resist building up a wheel shimmy that will be noticeable to the driver.

▸ Two Room Coolers

Announcements of what might be called the de luxe type of room coolers have been made within the past few days by General Electric and the DeLaVergne division of Baldwin-Southwark. Halftone illustrations of these two units are shown above to indicate the general type of structure adopted. Outside they are somewhat alike, inside they are quite different. The G.E. cooler comes in various forms, the floor type being shown here. Other types are the portable and wall variations of the simple cooler, coolers operating from remote compressors, complete air-conditioning units for year-round service, and central air-conditioning systems. The cooler dehumidifies the summer air and cools and circulates it. If portable it contains a compressor and must have electric and water connections. If fixed it must have connections for electricity and the refrigerant from the remote compressor.

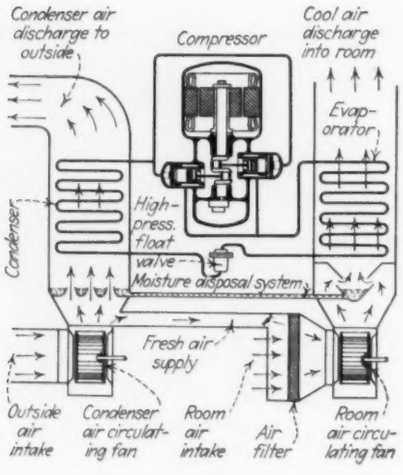
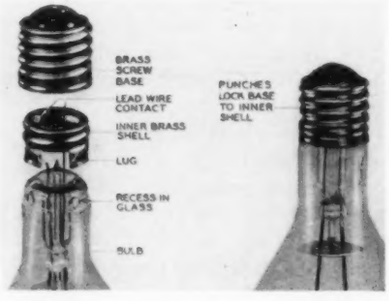


Diagram of the DeLaVergne reversible air-conditioning unit

The DeLaVergne unit is for year-round service and is completely self-contained. For cooling and dehumidifying it employs the customary compression refrigeration cycle. For heating and humidifying the new DeLaVergne reverse refrigeration cycle is used. A turn of a lever changes the unit from one cycle to the other. The unit is portable, its air ducts connecting with any partly raised window. An electrical connection is necessary. A diagram of the unit is shown here. The DeLaVergne two-cylinder opposed unit is driven by a 2-hp. vertical motor and will melt 1½ tons of ice per 24 hr. It is built to lower the temperature of a 5,000 cu.ft. room 10 to 15 deg. F., or to raise it that much when reversed. The G.E. unit has 1 ton capacity and a 2-hp. motor. A 2-ton compressor to supply remote units in two rooms is also available.

▸ New Lamp Base

For high-wattage floodlight and street lamps General Electric has developed the new mechanical base illustrated, to get away from the old troubles with cement. Four recesses are molded into the heavy glass of the bulb neck. Four lugs on the



A mechanical base for large lamp bulbs avoids the old cement troubles

inner brass shell snap into these recesses when the base is assembled. One lead wire is then welded to a pronged contact on the inner shell. After the outer brass shell has been screwed on and drawn up flush with the neck of the bulb the other lead wire is welded to the end of the base. Finally the inner and outer shells are pierced and locked together.

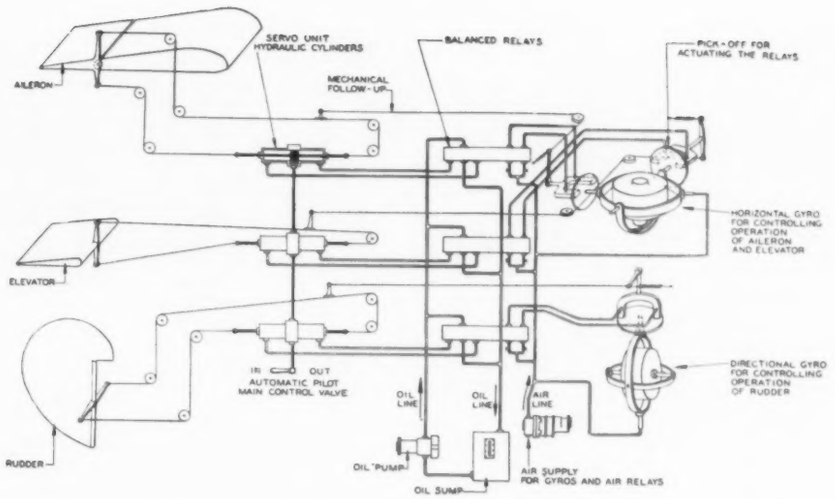


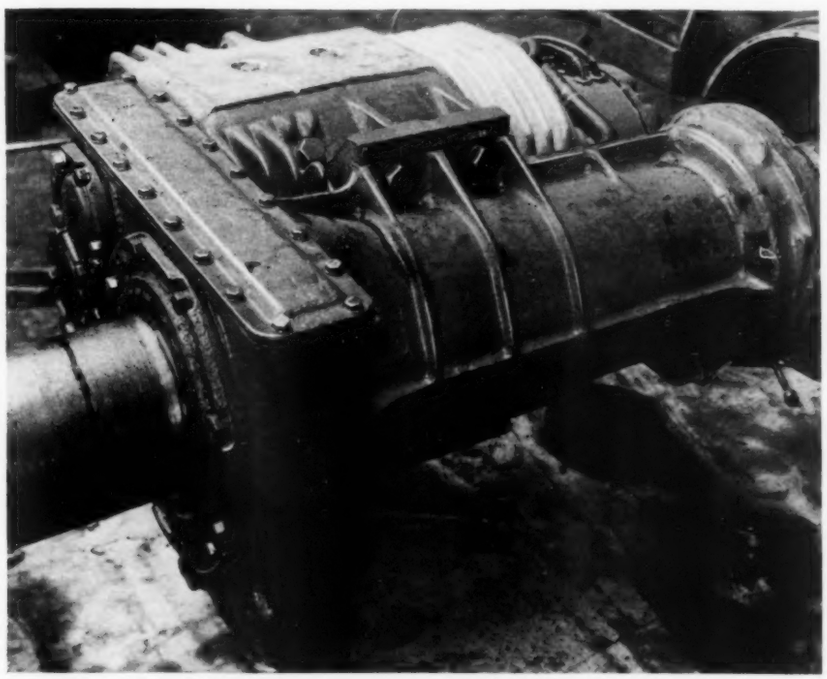
Diagram of Sperry automatic aircraft pilot. Servo unit hydraulic cylinders located close to the fire wall, to keep oil temperatures up, operate mechanical controls and are operated by pneumatic balanced relays with pneumatic pick-offs from the two gyroscopes, one for rudder, the other for ailerons and elevators

▸ Geared Drive for Axle Generator

Capacity demanded from axle generators by air conditioning service on railroad cars has crowded the limits of flat belts and turned attention to some other form of drive. Westinghouse generators for this work are designed to run 3.8 times the axle r.p.m., or 3,200 r.p.m. at 90 m.p.h. To get this reduction a single belt is inadequate. Either a combination belt and gear drive or direct gear drive would do, but the latter was chosen as being simpler and more compact.

The gear unit illustrated is a one-piece steel casting mounted on Timken bearings on a special car axle. Gears run in an oil bath, splash lubricating the gear bearings and the pinion-end generator bearings. The generator is splined and bolted to the gear unit to preserve correct alignment. Careful sealing keeps the oil in and dirt out. Helical gears with a high helix angle operate smoothly and quietly, three teeth being always in mesh. An all-metal slip clutch is built in to protect the unit if tooth loads exceed a predetermined maximum.

Two types of gear units are produced. One has an idler gear between axle gear and generator pinion, thus permitting a smaller axle gear to be used to reduce the height of the unit where clearances are small. In the other unit a larger gear is used and the idler is omitted. The extra height of this unit is 3 in.



Gear drive for air conditioning railroad car generator

Mercoid flow switch in this check valve shuts off pump if water fails

▸ Built-in Flow Switch

If the pump connected through Barrett, Haentjens' new check valve loses its water, the mercoid switch built into the valve opens and stops the pump. The switch can be arranged for mounting either vertically or horizontally. While water is flowing through the valve the flap is held open and the switch is kept closed. If the water stops, the flap falls, and in so doing opens the switch.

COMMUNICATION and COMMENT

Worm Gear Efficiency

To the Editor:

Mr. Brewster's article in the May number on "What to Specify for High-Efficiency Worm Drives" does not state how the high gear efficiency is obtained. Satisfactory worm gears have resulted from improvements in the technique for machining the contact surfaces. When appraising worm gearing it is extremely difficult for the average industrial user to measure the accuracy and finish of the worm threads and gear teeth, but users can find out the methods and machines used in the production of the worm gearing. There is, of course, no definite dividing line between satisfactory and unsatisfactory workmanship, the final criterion being the amount that the user is willing to pay in order to secure worm gears with a minimum coeffiicent of friction, and with the resulting increase in efficiency, dependability and long life.

Worm threads should be hardened and ground. This means more than a light casehardening followed by a smoothing operation on a grinding wheel. The hardened case should be sufficiently deep to permit the generation of the thread form on the grinding machine. A satisfactory job can only be secured on a sturdy and accurate thread-grinding machine with suitable means for keeping the wheel accurately dressed. The threads should not be polished by hand or other means after grinding, because such efforts are sure to produce inaccurate thread surfaces.

It is difficult to determine the accuracy of gear tooth generation through a study of methods and tools, but there are some essential factors that have a determining influence. The worm gear teeth must be formed by the hobbing process on a machine designed and built for this purpose. With such machine tool equipment the accuracy and finish of the teeth depend entirely on the quality and accuracy of the cutting tool, the hob. The best form of worm-gear hob is the conical type which can be fed tangentially across the gear blank in finishing the teeth. An indication of hob accuracy can be secured by considering the means by which the manufacturer maintains such accuracy. Proper hob-grinding equipment and close limits, beyond which the grinding of an old hob must not be carried, are important factors.

A finished gear can be checked for hobbing accuracy by mounting it at the operating center distance with its mating worm and noting the bearing between thread and tooth surfaces by the use of Prussian blue. It is sometimes said that such a test is no proper criterion because the parts will soon wear to a satisfactory bearing. There is always, of course, some initial wear in a worm gear on account of microscopic inaccuracies in the hard bronze surface, but a new gear should show a fairly symmetrical bearing on the teeth with a good proportion of the surfaces in contact. It is farcical to go to such limits in grinding and hobbing accuracy and then depend on operation wear to form proper tooth contours.

In worm gearing, the efficiency as well as the permissible tooth load depends to a great extent on lubrication. Mr. Brewster, in his article on worm drives in the May number, says nothing about this. From the standpoint of efficiency alone, an oil with a low viscosity would be preferable, but high tooth loads require a heavy-bodied oil. The maximum permissible tooth load is definitely limited by the maximum pressure at which a film of lubricant can be maintained between the rubbing surfaces. A proper lubricant must therefore be a compromise between these two requirements. The oil must be sufficiently liquid to form a film quickly, and to keep churning losses at a minimum; it must be sufficiently sticky to adhere to the contacting surfaces under comparatively high operating temperatures; and it must be sufficiently viscous to maintain an oil film under high tooth pressures encountered.

For general use at worm speeds below 2,000-r.p.m., a mineral-base oil with about 5 per cent acidless tallow, and a viscosity of 140 sec. Saybolt at 210 deg. F. is most satisfactory. For higher worm speeds a lower viscosity can be used.

Although the worm gear has an inherently lower efficiency than other well-made types, such as spur and herringbone gears, it is a fact that the worm gear does in many instances maintain its efficiency and give a longer operating life than other forms. This is explained by the fact that practically all the wear in a worm gear occurs on the bronze gear teeth. The hardened worm thread generates new and theoretically accurate contours on the gear teeth as wear continues, thus maintaining the initial efficiency throughout the life of the drive. This property of self-correction is perhaps the most valuable characteristic of the modern worm gear. —J. R. SAWYER

Cleveland, Ohio.

Rubber Rules

HOLLOWAY KILBORN

The Kilborn & Bishop Company

Constant length is usually considered a fundamental requirement of a scale, but a scale made of rubber has some interesting properties. When a strip of rubber carrying a uniform scale is stretched each division will be increased in proportion to the total length change. A useful calculating device can be built upon this property of uniform stretch. For instance, the number of lines of type on this page can be easily counted by stretching the rubber strip until the numbered scale divisions on the rule agree with the lines of type. Also, the rule can be used to divide a given space into any number of equal parts.

Combining a fixed log scale and a rubber log scale provides a tool for solving equations of the type

$$L = R^T D$$

The rubber rule can be set for any power T. Combining a fixed uniform scale and a rubber log scale gives logarithms to any base.

Special combinations of fixed and rubber rules will solve many design problems. For instance, the relation

between the volume and height of a liquid in a cylindrical tank lying on its side can be placed on a rubber rule so that the heights of a given quantity of liquid can be found for any diameter of tank. Further variations are possible by using a wedge-shaped rule in which the stretch would not be uniform.

Errors in a 12-inch rule stretched to double its length are said to be less than 1/16th in. maximum. It is recognized that the rubber rule is not a precision instrument, but its accuracy is well within the limits usually required for graphical calculations.

Reflectivity of Commercial Surfaces

To the Editor:

The color-reflectivity chart that appeared with an article, "Metals for Reflectors," in the April *Product Engineering*, gives data for a number of metals. How can this data be applied to the usual commercial materials and finishes? For instance, what is the reflectivity of the following surfaces?

Plain ternplate, unbuffed
Plain electro zinc-coated steel, unbuffed
Plain cadmium-plated steel
White enameled steel, vitreous
Bright nickel, buffed and colored
White nickel deposited on unbuffed surface and not colored
Chromium plate deposited on unbuffed surface and not colored
Sheet chromium steel, buffed out.

—A. VANDER HENST
Grand Rapids, Mich.

In answer to the above, according to a publication of the U. S. Bureau of Standards, the reflectivity of tin, zinc and cadmium surfaces under vertical light within the visible color range are:

tin .....72 to 81 per cent
zinc .....97 to 98 per cent
cadmium .....96 to 98 per cent

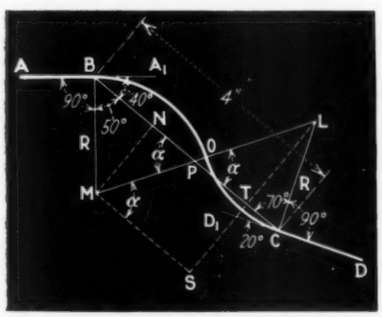
In regard to the other surfaces listed, there is but little information available. If any readers have such information, their contributions would be of interest.

Analytical Solution to the Reverse Curve Problem

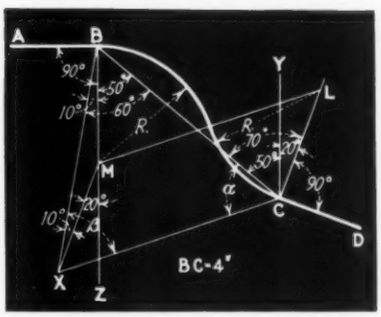
In the April number Dean E. Hobart submitted the problem of locating the centers of two arcs forming a reverse curve between two non-parallel lines. The two arcs were to be tangent to the two lines and of equal radius, and a graphical solution as well as an analytical solution was required. Several analytical solutions have been received, two of which are presented here. Another contribution including both the geometrical and analytical solution for the general case will be presented in the July number.

To the Editor:

Assuming M and L are centers of curvature, draw MN and LS perpendicular to BC and MS parallel to BC.



Short analytical solution to the reverse curve problem



Another analytical solution for obtaining the reversed curves of equal radius

$$BC = 4 \text{ in.}$$
$$= R \cos 50 + R \cos 70 + 2R \cos \alpha$$
$$R = \frac{4}{\cos 50 + \cos 70 + 2R \cos \alpha}$$
$$SL = ML \sin \alpha$$
$$= 2R \sin \alpha$$
$$SL = LT + MN$$
$$= R \sin 50 + R \sin 70$$
$$2R \sin \alpha = R \sin 50 + R \sin 70$$
$$\sin \alpha = \tfrac{1}{2}(\sin 50 + \sin 70)$$
$$= 58° - 31' - 30''$$

Substituting this value of α in the equation for R gives a value of R=1.971 inches. —A. T. FLIEDNER
Cleveland, Ohio

To the Editor:

Referring to the figure for the data given, draw perpendiculars BZ and CL. The centers of the required arcs will fall on these lines. Draw CY parallel to BZ forming an angle of 50 deg. with BC and 20 deg. with CL.

Along BZ lay off a distance BM approximately equal to R, and lay off the same distance on CL. By a process of trial and error the distance is chosen so that LM equals $2R$. The exact value of R is then determined as follows:

Draw MX equal to CL and forming an angle of 20 deg. with MZ. Draw CX forming the parallelogram $CLMX$ in which $LM=2R$. Draw BX making an isosceles triangle MBX in which the small angle is 10 deg. since the exterior angle of a triangle is equal to the sum of the other two interior angles.

In the triangle BCX, angle α is found by the sine rule as follows:

$$\frac{CX}{\sin 60°} = \frac{BX}{\sin \alpha}$$
$$BX = 2R \cos 10°$$
$$\frac{2R}{\sin 60} = \frac{2R \cos 10}{\sin \alpha}$$
$$\sin \alpha = \sin 60 \cos 10$$
$$\alpha = 58° 31'$$

Using the same method on angle β

$$\frac{CX}{\sin 60} = \frac{BC}{\sin \beta}$$
$$\frac{2R}{\sin 60} = \frac{4}{\sin (180 - 60 - 58° 31')}$$
$$= \frac{4}{\sin 61°29'}$$
$$R = \frac{2 \sin 60}{\sin 61°29'}$$
$$= 1.971 \text{ in. radius}$$

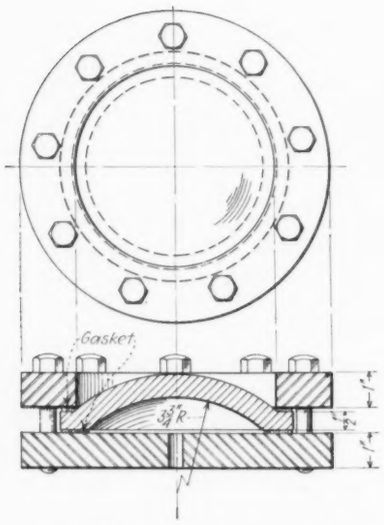
The centers of the arcs are obtained by laying off the distance 1.971 in. along the lines BM and CL.

—N. M. WICKSTRAND
Meriden, Conn.

Stresses in Curved Disks

To the Editor:

To my knowledge there is no simple mathematical formula, in readily usable form, for obtaining the maximum tensile stresses in a curved circular



Is there a simple formula for the maximum working stresses in a dished head such as this one?

plate clamped around the edge and exposed to uniform pressure on the concave side. Such a formula would be of value in determining the working stresses in constructions such as the one illustrated.

Any formula developed must take into account both the effect of various degrees of clamping and the curvature of the disk. The tensile stresses in a uniformly loaded flat circular plate and simply supported at the edges, are greater for a given load than for a plate rigidly supported around the edges. Extremely loose and tight clamping may be expected to correspond to these limits. Likewise, the initial curvature will have an effect similar to that in curved beams. Finally, account must be taken of the shearing action which exists just inside the inner edge of the clamping ring.

Although empirical formulas have been developed to satisfy particular situations, it would be an advantage to have a more general treatment of the problem. If such an analysis has been made, I would like to know about it. —C. J. PHILLIPS

Corning, New York

Simplified Calculation for Twist of Shafts

J. S. CARPENTER

The problem of calculating shaft twists is one that comes so infrequently that when the necessity arises considerable time may be lost in referring to handbooks or texts. The following formulas and table have been developed to shorten the calculations so that a shaft design can be checked quickly for twist.

The twisting moment is the product of the twisting force and the radius at which it acts. In the following formulas these notations are used:

P is the twisting force in lb.
R is the radius of P in in.
S is the shear stress in lb. per sq.in.
L is the length in in. between the twisting arms
D is the twist in deg.
G is the torsional modulus, 12 million lb. per sq.in.
d is the shaft diameter in in.

The handbook formulas reduce to the form,

$$D = 585\ PRL/Gd^4$$

The resultant shear stress reduces to

$$S = 104{,}700\ Dd/L$$

Solving this equation for d,

$$d = 0.0835\ (PRL/D)^{\frac{1}{4}} = K\ (PRL)^{\frac{1}{4}}$$

This gives a value of

$$K = d/(PRL)^{\frac{1}{4}}$$

The table herewith gives values of K as calculated from the above formula. In designing shafts, the maximum allowable angle of twist is determined and the value of K corresponding to this angle of twist is obtained from the table. The value of D is then calculated from Equation (1).

For convenience in the drawing room, a curve can be constructed using K as ordinates and D as abscissas.

Shaft Twist

Values of K for angles of twist

D	K	D	K
0.25	0.1180	4.00	0.0591
0.50	0.0991	4.50	0.0574
0.75	0.0896	5.00	0.0558
1.00	0.0835	5.50	0.0545
1.50	0.0755	6.00	0.0534
2.00	0.0703	7.00	0.0514
2.50	0.0665	8.00	0.0497
3.00	0.0635	9.00	0.0482
3.50	0.0612	10.00	0.0470

Erratum

In the Reference Book Sheet appearing on page 199, of the May *Product Engineering*, the dimension lines A and A_1 should include the 1/64-in. thickness of the washer face.

DEFLECTIONS

THE HIGH COST OF WEIGHT

A recent number of *Udylite News* states that in airplanes it is worth anywhere from $1.00 to $50.00 per lb. to save weight, and points out that steel heat-treated to a strength of more than 150,000 lb. per sq.in. is lighter as a structural material than dural or other aluminum alloys. The thin steel tubes are cadmium plated to prevent corrosion.

MOSQUITO POWER

At a distance of a few hundred miles from a transmitting station, a radio receiving set receives only a hundred trillionth of the total power sent out by the broadcasting station. As explained by Dr. Irving Langmuir, of the General Electric Company, the 50-kilowatt power sent out in radio signals is equivalent to lifting a one-ton weight at a rate of 12 miles an hour; the power received at the radio set is the amount a mosquito would require to climb at about 2 ft. a minute.

OIL ON TROUBLED WATERS

A soft drink vending machine was developed to uncap the bottled liquid and pour it into a paper cup to dispense it. Tested with water the device functioned perfectly, but when the beverage was tried it foamed so much that it was impossible to save more than half the contents of a cup. Various expedients were tried but all were unsuccessful until a religiously inclined individual be thought himself of the oil on troubled waters and tried a paraffined cup. The slight amount of residual oil on the surface of the treated paper of a moderately fresh cup formed an invisible and tasteless film on the surface of the beverage and prevented the foaming.

SUPERFINE MEASUREMENTS

A skilled mechanic with a steel scale can measure to about 1/100 of an inch. With a micrometer he can measure nearly to 1/10,000 in. Electric gages will indicate 1/1,000,000 of an in., but the prize goes to the X-ray spectrograph described by Mr. Hawkins, executive engineer of the General Electric Research Laboratory. This instrument measures distances 100,000 times smaller than those the electric gage can indicate, a distance so small that it bears to 1 in. the same ratio that 1/100 in. bears to the diameter of the earth.

· NEWS ·

Styling and Simplification for New Products

Modernization of styles and of manufacturing methods featured the second annual New Products exhibition and meeting held at Boston May 11-12 under the auspices of the New England Council. Norman Bel Geddes addressed the opening session, stressing the importance of linking beauty in commodity designs with economical production and featuring the various stages in the development of a new gas range. Following an exhaustive study of consumer opinion and wants, production problems were considered with the objective of manufacturing and marketing a salable stove at reasonable cost. Previously the client was selling 140 models requiring over 1,000 units to build, a unit being considered as an oven, broiler, utility compartment, etc., regardless of the number of individual parts required. New units were so designed that by the use of various combinations and sizes, enough flexibility would be realized to meet sales requirements, the number of units necessary to stock being cut to about 30. Not until this point in the development had been reached was a sketch made of the finished article.

Construction features of the stove include the use of a tubular steel framework to replace cast-iron and the substitution of welding for bolts. The reduced construction costs made it possible to utilize the best grade of enamel, employ aluminum foil, flush drawers and bakelite handles and still sell the stove at a price below any comparable product. Reports of the first two months' sales have been most gratifying.

Dr. H. C. Parmelee, vice-president McGraw-Hill Publishing Company, Inc., gave a lantern slide talk featuring approximately two dozen new product developments which have been made in industrial and scientific fields during the depression, many of which have already led to increased consumer buying. "Research has established a salient on the industrial front," the speaker declared, "and the time has arrived to rectify the commercial battle line and consolidate the gains achieved by massing purchasing power for effective satisfaction of human needs. No traffic light can be pulled on human ingenuity, even in periods of depression," he asserted.

Eighty displays of the latest ideas in consumer goods featured the exhibit. Styling was a major factor in the sales appeal, but this was achieved in the main without complicating production processes. Among the displays of interest to industrialists were electric clocks with reduced size motors and compact gearing assemblies; rope matting; a new electric sizing device; a conjugate cam grinding machine designed to grind 16 cams simultaneously and in less than 60 seconds; new abrasive products; an alundum rubber-bonded safety tread; and a fiber and cork rug holder to prevent slippage on floors.

New A.S.A. Bolt and Nut Standards

A revision of the American Tentative Standard for Wrench-Head Bolts and Nuts and Wrench Openings (B18b-1927) has been approved by the American Standards Association as the American Standard B18.2-1933. This revision differs from the 1927 edition mainly in that tables for "heavy" bolt heads and nuts have been added to the original smaller "regular" series. The new standard contains eight tables covering the following subjects:

1. Square and hexagon bolt heads (unfinished, semi-finished, and finished) in the regular series (sizes $\frac{1}{4}$ to 3 in.), and in the heavy series (sizes $\frac{1}{2}$ to 3 in.).

2. Square and hexagon nuts and jam nuts (unfinished, semi-finished, and finished) in the regular series (sizes $\frac{1}{4}$ to 3 in.), and in the heavy series (sizes $\frac{1}{2}$ to 4 in.).

3. Light nuts (hexagon, semi-finished), in sizes $\frac{1}{4}$ to $1\frac{1}{2}$ in.

4. Capscrew heads (hexagon), sizes $\frac{1}{4}$ to $1\frac{1}{4}$ in.

5. Light castle nuts (hexagon), sizes $\frac{1}{4}$ to $1\frac{1}{2}$ in.

6. Machine screw and stove-bolt nuts (square and hexagon) in numbered sizes (0 to 12), and $\frac{1}{4}$, $\frac{5}{16}$, and $\frac{3}{8}$ in.

7. Setscrew heads (square), sizes $\frac{1}{4}$ to $1\frac{1}{2}$ in.

8. Open end wrench openings for regular, heavy, and light series of bolt heads and nuts.

The American Society of Mechanical Engineers and the Society of Automotive Engineers are sponsors for the project. The standard is being published by the American Society of Mechanical Engineers and may be purchased from the A.S.M.E., the S.A.E. or from the American Standards Association, 29 West 39th Street, New York, at 45 cents per copy.

MEETINGS

American Institute of Electrical Engineers — Semi-annual meeting, June 26-30, Chicago, Ill. H. H. Henline, secretary, 33 West 39th St., New York, N. Y.

American Foundrymen's Association—Convention, June 20-23, Chicago, Ill. Robert E. Kennedy, secretary, 222 W. Adams St., Chicago, Ill.

American Society of Mechanical Engineers — Semi-annual meeting, June 26-29, Hotel Stevens, Chicago, Ill. Calvin W. Rice, secretary, 29 West 39th St., New York, N. Y.

American Society for Testing Materials — Annual meeting, Chicago, Ill., June 26-30. R. E. Hess, assistant secretary, 1315 Spruce St., Philadelphia, Pa.

Society of Automotive Engineers—International Automotive Congress, Aug. 28-Sept. 4, Palmer House, Chicago, Ill. John A. C. Warner, general manager, 29 West 39th St., New York, N. Y.

EXHIBITIONS

American Oil Burner Association—Tenth National Show, June 12-16, Chicago, Ill. H. F. Tappe, secretary, 342 Madison Ave., New York, N. Y.

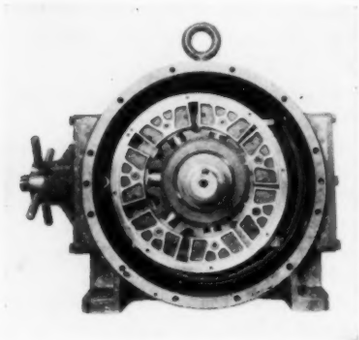
Foundry & Industrial Exposition—Exhibition Hall, Stevens Hotel, Chicago, Ill., June 20-23.

Sixth Midwest Engineering and Power Exposition—Coliseum, Chicago, Ill., during "Engineering Week" of Century of Progress Exposition, June 25-30. Headquarters, 308 W. Washington St., Chicago.

NEW MATERIALS and PARTS

Northern Hydraulic Pump

Is a rotary radial piston pump for hydraulic control of machines, and for use as a variable speed drive or hydraulic motor. The discharge volume can be varied from maximum to zero and reversed without changing speed of rotation or stopping pumps. The revolving cylinder block is a one piece



nitralloy forging rotating on two roller bearings. Both piston and piston sleeve are of nitralloy, and flat crosshead surfaces are lubricated by oil from the piston sleeves. Piston pin is supported by a cast bronze shoe with the oscillating load taken through needle bearings. Bronze shoe is of sufficient mass that centrifugal force holds it against a polished steel ring except when starting. Manufacturer claims that a maximum efficiency of 92 per cent is reached at 1,500 lb. per sq.in., with but little decrease at 3,000 lb. per sq.in., that balanced pressure design reduces heavy bearing load at high pressures, and close clearances permit use of wide range of lubricating oils. Available in six sizes with capacities from 1 to 200 gal. per min., and pressures up to 4,000 lb. per sq.in. Also available with automatic control interchangeable with standard hand control. Northern Pump Co., Minneapolis, Minn.

Goodrich Gasoline Pump Hose

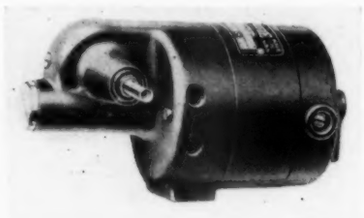
With a new Permalock coupling designed to prevent leakage at the coupling. Hose consists of a metal lining constructed so that rubber is not forced into convolutions of the metal during braiding and wrapping. A braid of heavy yarn covered by a layer of black rubber resists abrasion and protects hose from wear against concrete. The Permalock coupling is permanently locked into the hose. Manufacturer states that the hose will not discolor the hands of the operator, or rub off against finish of the car, and the rubber covering can be cleaned by wiping with a cloth moistened in gasoline. Claimed that no rubber can get into the gasoline, that no gasoline can leak through the coupling, and soften the rubber. Bursting strength is said to be approximately 1,000 pounds, and hose retains flexibility during wet weather since moisture cannot penetrate the cover. The B. F. Goodrich Rubber Co., Akron, Ohio.

General Electric Oil- and Heat-Resisting Cable

Insulated with Glyptal-treated cloth is said to resist oil and withstand high temperatures, and to have flexibility and toughness to withstand severe mechanical strain. Glyptal is a synthetic resin unaffected by mineral oil. Claimed that Glyptal-treated cloth will withstand temperatures of 100 deg. C. for several months without appreciable deterioration, and will retain its dielectric strength for a long period of time under mechanical abuse. Cable insulated with Glyptal-treated cloth is applicable to low- and medium-voltage leads, apparatus cable, transformer leads, coil leads and control circuits, or where an oil-resisting, heat-resisting cable is required. General Electric Co., Schenectady, N. Y.

Three New Dumore Motors

Series K-3 is a universal motor rated at $\frac{1}{4}$ hp. for 30 min. at 5,500 r.p.m., and $\frac{1}{8}$ hp. for continuous duty at 6,500 r.p.m. Series J-3 is similar to K-3 except in design of housing and ventilation. These motors were especially designed for portable electric tools and appliances. The EEXQ motor here illustrated is a dynamically balanced, slow-speed universal motor



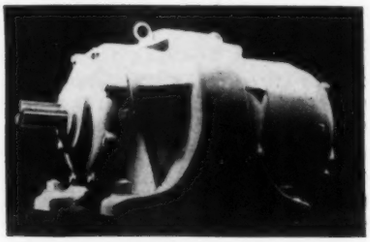
with a built-in. single worm gear reduction. Standard gear ratios of 15:1, 30:1, and 40:1 are available, giving shaft speeds of approximately 200 to 750 r.p.m. The Dumore Co., Racine, Wis.

Westinghouse Electric Valve

Will automatically seal an airplane gasoline line when the ignition is turned off; can also be used on air-conditioning apparatus, vacuum pumps, punch presses. Valve consists of an inner steel core, and a hollow outer tube which is an integral part of the pipe line. The inner core piece is held away from the valve seat by an electromagnet. When the electric circuit is broken, a spring causes the plunger to seal the valve. Claimed that leakage in the valve is eliminated by a flanged, flared-tube seal, with no stuffing boxes or gaskets. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

U.S. Synchrongear

Is a self-contained, single-base, geared transmission, mounted on a heavy pedestal base to withstand the torsional stresses present in geared high torque reductions. Anti-friction bearings and helical gears are used

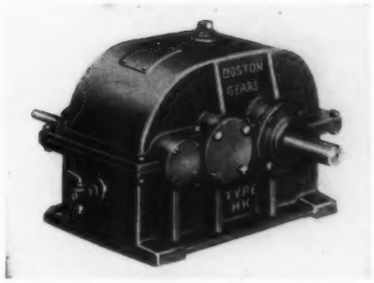


throughout; cast-iron parts are normalized to insure permanent alignment of gears. Main bearing supports cast integral with base. Designed so that either the gears or the motor can be inspected or removed without disturbing other members. High-speed gears dip into oil reservoir. Claimed that pedestal construction minimizes cantilever stresses from overhung gears. Primary drive provided by U. S. Auto-Start Motors with one-piece die-cast construction and asbestos insulated windings. Available with final drive speeds of 2 to 18,000 r.p.m. U.S. Electrical Mfg. Co., Los Angeles, Calif.

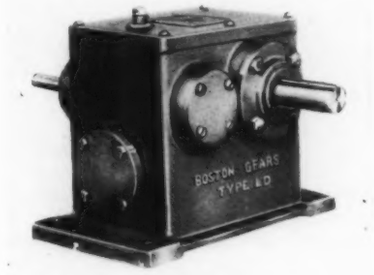
Three Boston Worm Gear Speed Reducers

The smallest of the line is available in ratios from 10 to 1 up to 100 to 1, with ratings of $\frac{1}{8}$ to 3 hp., supplied with a.c. motors if required. Timken tapered roller bearings are used on both high and low-speed shafts. Oversize shafts make outboard bearings unnecessary. The design with the worm above the gear is claimed to give greater strength and to make the reducer leakproof when oil is kept at a proper level.

Compound worm gear type LD adapted for slow moving driven members such as stoker and conveyor drives, is available in ratios from 37.5 to 1740 to 1. Gears are of cast bronze and worms are hardened steel with threads ground. Equipped with Timken tapered roller bearings. Compound helical type HK available in ratios from 9.79 to 84 to 1. Also equipped with Timken taper roller bearings, lubricated by the splash system. Boston Gear Works, Inc., North Quincy, Mass.



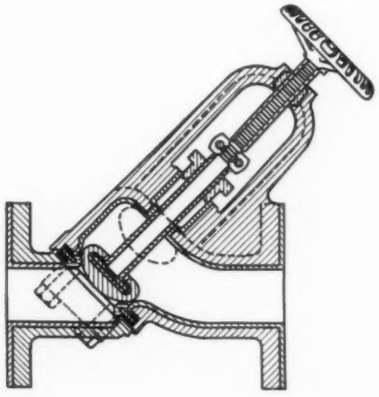
Compound helical type HK

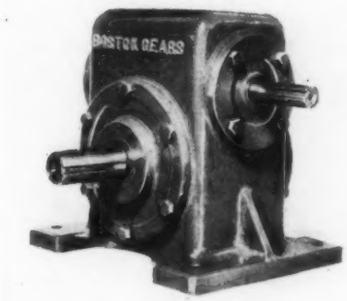


Compound worm gear type LD

Goodrich Vulcalock Valve

Is a rubber-lined valve for handling corrosive and abrasive fluids under conditions of fairly high pressure, pulsating pressure, throttling or suction. Available with any of the standard Goodrich Acidseal rubber linings. Corrosive or abrasive materials come in contact only with rubber, and on sizes up to and including 6 in. there is no restriction of flow through the seat rings. The valve can be changed from a straight-away to angle by reversing the lower body section. Valve disk, made of resilient material, snaps over the circular plate at the lower end of the valve stem and seats against a molded reversible ring. Bronze operating screw engages threaded bushing of bearing bronze cast into the iron yoke, and is attached to the upper end of the valve stem by a swivel coupling.





Small speed reducer

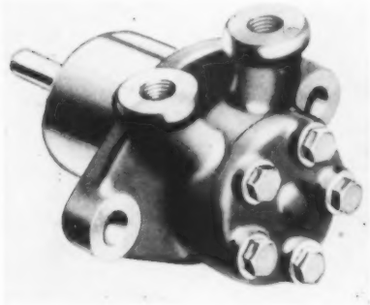
The stuffing-box is cast integral with the upper section of body. When valve is in wide open position, back of resilient disk seals off stuffing box. Claimed that packing can be replaced while valve is under pressure, and that disk and seat can be easily removed and replaced. Valve can be taken apart and assembled without special tools. The B. F. Goodrich Rubber Co., Akron, Ohio.

Gatke Moulded Non-Metallic Bearings

Used for a number of years for steel mill service, are now available in a complete line for general machinery uses. These non-metallic bearings, made in three types, are composed of a textile base impregnated with synthetic resins, moulded under high pressure. Hydrotex bearings are recommended for bearings run in water or where water is available for lubrication. Lubritex bearings are designed for equipment that is oil-lubricated. Grafitex type is self-lubricating, made for slow moving machinery, or where lubrication is neglected. Claimed that characteristics do not change with age, and no deterioration occurs if machinery is idle or bearings are neglected. Manufacturer states that they have a low co-efficient of friction and are not affected by ordinary acids, chemicals, solvents, or salt water, or softened by oils or greases. Available for journal diameters from $\frac{1}{8}$ in. to 24 in. Gatke Corporation, 228 S. LaSalle St., Chicago, Ill.

Sundstrand Rota-Roll Pump

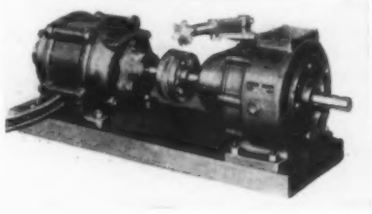
With either flange or foot mounting for applications to oil burners. Pump consists of a roller and rotor which revolve with each other and pump by



means of a rotary seal, the fluid being emptied ahead of the seal through the outlet port. Claimed that the roller and rotor are hydraulically balanced and self-emptying, preventing backsurging and leakage, providing a positive uniform flow; also, that the rolling seal and close manufacturing tolerances result in high vacuum. Available with a capacity of 18 gal. per hour at 100 lb. pressure at a speed of 1,800 r.p.m. Sundstrand Machine Tool Co., Rockford, Ill.

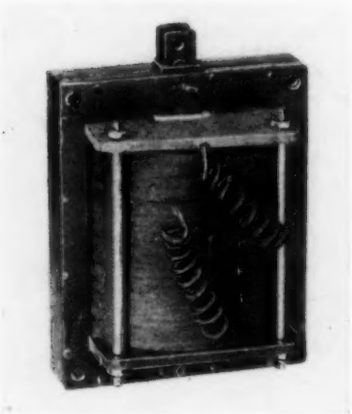
Johnson Variable Reducer

Approximately the same size as the driving motor uses five one-way overrunning clutches transmitting power in uniform cycles to a centrally mounted driven gear. Speed change is made by a variable throw crank-



shaft controlled by the hand lever which changes the stroke of the five arms attached to the one-way clutches. The lever control can be locked in any position with a small hand wheel, and a visible dial indicates the speed of the output shaft. The extreme low speed position gives zero speeds, the equivalent of a disconnecting clutch. When operated by a 1,200-r.p.m. motor, the speed range is from 0 to 240 r.p.m. Available in capacities from 1 hp. up. The Smith Power Transmission Co., Penton Bldg., Cleveland, Ohio.

Trombetta Solenoids

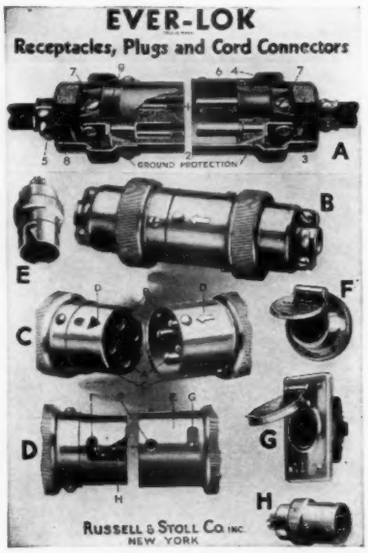


For applications requiring a small force acting over a short distance. Can often be substituted for more complicated mechanisms. Claimed to operate 200 times per min. Available in four standard sizes. For use on a.c. or d.c. Wrought Washer Mfg. Co., 2100 S. Bay St., Milwaukee, Wis.

Pull	Stroke	Dimensions
5 lb.	1¾ in.	4⅝x3⅝x3 in.
10 lb.	2½ in.	6⅜x4⅞x3⅞ in.
20 lb.	3½ in.	8⅝x6¾x5⅝ in.
40 lb.	5 in.	10⅞x8¼x6⅝ in.

Ever-Lok Equipment

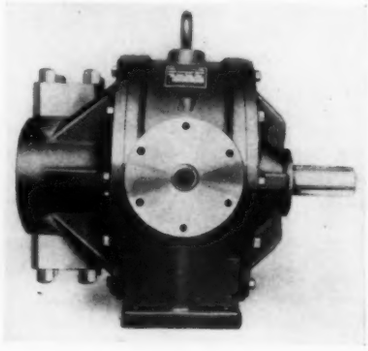
Includes receptacles, plugs and cord connectors approved by the Underwriters Laboratories. Referring to the illustration, automatic locking type, *D*, relieves strain from electrical contacts; positive grounding type, *A*, uses double phosphor bronze springs; dustproof type, *A-3*, has a sponge rubber washer which serves as a bushing and a shield. Receptacles are sealed to conduit boxes by gaskets, and have hinged flap doors which are gasket-lined, as illustrated in *F* and *G*. All fittings have cadmium-galvanized steel housings. Plugs and connectors have adjustable cord grips as shown in *A-5*. Electrical contacts are machined, self-wiping and self-aligning. Shell caps



are fibre-lined, and all interiors are of molded bakelite. Receptacles are adaptable to standard conduit boxes. Russell & Stoll Co., 53 Rose St., New York, N. Y.

H-P-M Pump

A radial pump for application to heavy duty production machines requiring high pressures, is of the positive displacement, multiple radial plunger type. The output is variable in volume, and reversible in direction of flow. Claimed to have high efficiencies, smooth delivery, vibrationless operation, positive displacement



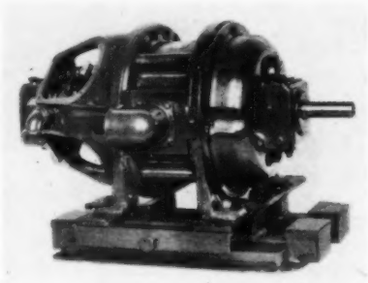
throughout suction and delivery. Available in six sizes from 1 gal. per min. to 100 gal. per min., at pressures up to 3,000 lb. per sq.in. The Hydraulic Press Mfg. Co., Mount Gilead, Ohio.

Durichlor

Is a new alloy said to be highly resistant to hydrochloric acid at all concentrations and all temperatures up to the boiling point. Alloy is comparatively inexpensive and is applicable to pumps, valves, pipe, fittings, jets and other chemical handling equipment. The Duriron Co., Inc., Dayton, Ohio.

G. E. Sound-Isolating Motor Base

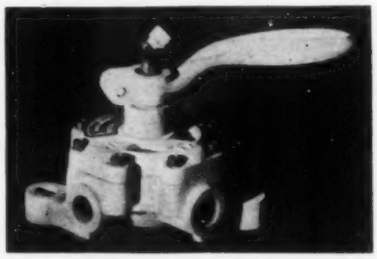
For use with the new line of quiet-operating motors where machinery vibrations at audible frequencies are objectionable. The motor is mounted on a sliding base maintaining belt tension in the ordinary manner. Floating members are suspended on specially developed isolating material, inclosed and mounted to insure long life and freedom from damage. Guide washers in machined grooves maintain motor alignment. Claimed that the stiffness of the sound-isolating material is sufficient to maintain motor alignment for any reasonable belt tension. When used with a motor for



which designed, isolating bases are claimed to be effective at any motor speeds from 100 per cent to 66 per cent of normal. Bases are available for polyphase induction motors of 1 to 50 hp., 900 r.p.m.; ¾ to 30 hp., 1200 r.p.m.; 1 to 3 hp., 1800 r.p.m. Single-phase motors of ½ to 2 hp., 900 r.p.m.; ½ to 2 hp., 1200 r.p.m.; 1 to 5 hp., 1800 r.p.m. General Electric Co., Schenectady, N. Y.

Hanna Unitite Valve

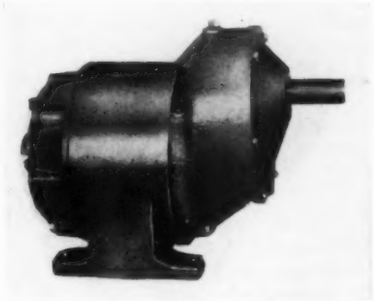
For air, oil or water at pressures up to 250 lb. per sq.in. Can be used as a straightway, 3-way or 4-way valve, with the operating handle adjusted to any position on the stem. Full port opening obtained with a 40-deg. move-



ment of operating handle; a reversal with an 80-deg. movement. The two-piece disk and the stem rotate as a unit, lubricated from a well in the stem. Valve seat is in the bonnet allowing valve to be reground without disconnecting piping. Bonnet is secured to body with socket-head capscrews and sealed with a lead gasket. Claimed that scoring is prevented by rotating disks on two eccentric points when in contact with the seats, and that wear is uniformly distributed, that disk is free to find its own seat and cannot be unseated by a lateral force. Hanna Engineering Works, 1765 Elston Ave., Chicago, Ill.

Westinghouse Type S Gearmotors

Use fully inclosed helical gears running in an oil bath. The units are designed for drives from ½ to 75 hp., and are available with 14 reduction ratios from 1.12:1 to 5.1, giving final



speeds of 1,550 to 232 r.p.m. Gear reductions can be readily changed at small cost. It is claimed that since the unit is but little longer than a motor, substantial economies are possible in equipment design, space requirements and power consumption. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Nichrome V

Is a new series of heat-resistant alloys of nickel and chromium, for electrical heating elements for furnaces, hot water heaters, ranges, electric appliances. Is said to withstand higher temperatures and to have longer life than other Nichrome alloys. Driver-Harris Co., Harrison, N. J.

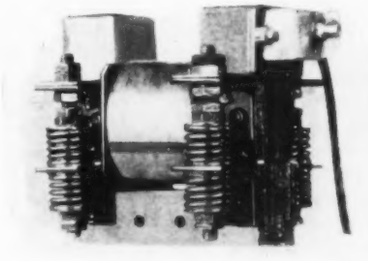
Brown Compensated Air Cell

Is a wet type non-rechargeable battery with a constant current output for use with the Brown potentiometer to eliminate frequent standardizing.

Battery is shipped dry and rendered active by adding cool drinking water. Operates on the principle of air polarization, the oxygen being obtained from the air rather than from compounds within the battery. The cell is equipped with a built-in coil which automatically compensates for changes in temperature. Claimed that a Brown potentiometer equipped with this cell will operate one month without standardizing. Manufacturer states that the life of the cell is over 2½ years. Brown Instrument Co., Philadelphia, Pa.

Belden Luster Cord

Is an all-rubber lamp cord, carrying a special lacquer finish in old gold, bronze, silver, and green. Cord is furnished on spools or in lengths equipped with unbreakable soft rubber plugs, tinted to match the cord. Also available for household repairs or replacements in lengths of 6½ ft., including attached soft rubber plug and connector caps. Any Belden rubber-sheathed conductor can be provided with these special finishes. Belden Mfg. Co., 4689 W. Van Buren St., Chicago, Ill.

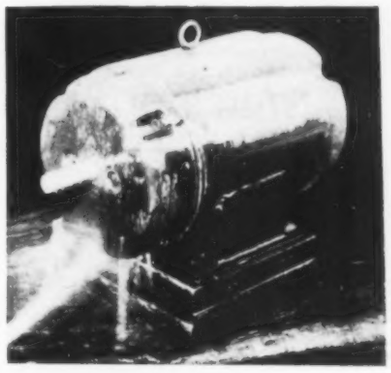


Syntron Electro-Magnetic Vibrator

Available in sizes from 5 lb. to 120 lb. for use on 110 or 220 volt, single phase, a.c. A rectifier controller supplies pulsating d.c. to a field, setting up vibrations in a spring-mounted armature. The linear vibrations produced can be applied to the work in any direction desired. Suitable for application to packaging machinery, conveyors. Current requirements vary from ½ amp. for the 5-lb. size to 20 amp. for the 120-lb. size. Syntron Co., 400 N. Lexington Ave., Pittsburgh, Pa.

Ideal Splash Proof Motor

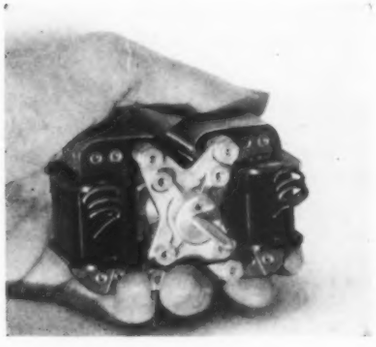
Especially designed for use in breweries, dairy plants, and places where water or other liquids may be splashed on the motor. Claimed that baffles placed in the air ducts remove all spray from the air entering the motor and keep the motor windings dry at all times, giving the protection of a totally enclosed motor. Available as squirrel cage induction motors in sizes from 1 to 200 hp. Also available as



across-the-line start motors up to 200 hp., supplied as unity or 80 per cent leading power factor induction motors in all sizes. The Ideal Electric and Manufacturing Co., Mansfield, Ohio.

Barcol Midget Four-Pole Motor

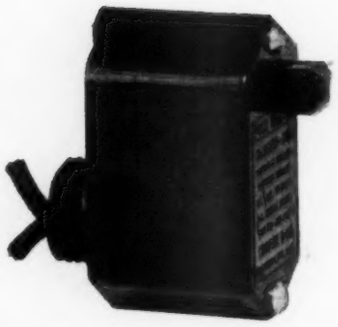
Is suitable for driving small pumps, advertising devices, and fans for cooling, exhaust, or heating. The no-load speed is about 1,700 r.p.m. At full load the motor delivers 0.0035 hp. at 1,300 r.p.m., with an input of 23 watts at 115 volts 60 cycles. The starting torque is 0.2 lb. The current drawn by the motor when stalled is but little more than when running at full load.



Motor dimensions are 3x2¼x1 in. The shaft, located in the center of the two largest dimensions, runs in oilless bearings, and is 0.1845 in. in diameter. Available in a variety of voltage and frequency requirements. Barber-Colman Company, Rockford, Ill.

Square D Knockout Breaker

Is an overload protective relay for small single-phase motors. Body of black bakelite has a threaded extention that mounts into a standard ½ in. knockout. Relay is of the melting alloy type with silver-to-silver, double-break contacts opening a single circuit. After an overload trips the breaker, it is manually reset by an indicating button. No replacement parts are required. Claimed that the heater unit will trip the breaker at a fixed current



value providing an ample time interval to take care of momentary overloads without tripping. Class 9020—Type W10 breaker complete with heating coil is 1⅜ in. wide, 2 7/16 in. high, 1¾ in. deep. Available with a rating of ¾ hp., 110-220 V., single phase, ⅓ hp., 115 V., d.c. Square D Co., Industrial Controller Division, Milwaukee, Wis.

NEW BOOKS and PUBLICATIONS

American Standards Year Book for 1932-1933

A review of standardization aims and activities. 44-pages, 7¾x10 in. Issued by the American Standards Assocation, 29 W. 39th St., New York, N. Y. Copies available free of charge.

The Year Book reveals the significant fact that standardization projects have gone forward during the past year despite business conditions. A total of 31 new standards are listed.

Daniel C. Roper, United States Secretary of Commerce, in a foreword to the Year Book points out the importance of industrial standards in commerce. Another section of the report describes the method by which American Standards are developed, and outlines the plan of organization and cooperation by which industrial standardization is obtained.

The Year Book includes an index and a list of completed and uncompleted A.S.A. projects, including such information as the scope, sponsors, and officers for each of the standardization activities.

The Technical Man Sells His Services

Edward Hurst. 239 pages, 5½x8 in. Bound in cloth boards. Published by McGraw-Hill Book Co., Inc., New York and London. Price $2.

Mr. Hurst has had pronounced success in his lectures to seniors at Massachusetts Institute of Technology on how to get a job. This volume is based on his lectures and has been tried at M.I.T. as a private edition for the class of 1933. After outlining his thesis that the technical graduate must sell himself to his prospective employer as a profitable investment, Mr. Hurst tells how to plan for the crucial interview. He then gives complete details of ten cases including all the different types of technical preparation, from civil engineering to financial management.

In his preface the author remarks that writing is not his profession. The casual character of his punctuation and construction is sufficient proof of the truth of his admission from a narrowly technical viewpoint. A little editing would have helped considerably. Yet the presentation of his ten cases is so realistic and human that the reader soon forgets the minor faults.

If there is anything that is open to criticism it is the facility with which callow graduates acquire $3,000 jobs in several of his cases. To the captious this may have just a touch of the Horatio Alger style. In spite of this drawback the book should prove of real value to the young engineer who has to find a place in the outside world when he leaves college. Many an older engineer could profit by a study of the principles involved.

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Ball Bearing—Bantam Ball Bearing Co., South Bend, Ind. 8-page bulletin, "Engineering Data for Bantam Roller Bearings Using Small Diameter Rollers," includes illustrations of many applications, formulas and charts for design calculations.

Chain Drives—Chain Belt Co., Milwaukee, Wis. Buletin 231, "Rex Chains," describing a complete line of chains and transmission equipment.

Electrical Supplies—Trumbull Electric & Mfg. Co., Plainville, Conn. Revised pages for Trumbull catalog.

Fabrikoid—E. I. duPont de Nemours & Co., Wilmington, Del. 32-page book bound in Fabrikoid, "The Story of Fabrikoid PX Cloth," describing its use in bookbinding.

Locknuts—American Gas Accumulator Co., Elastic Stop Division, Elizabeth, N. J. 10-page booklet, "Technical Data on the Use of Elastic Stop Nuts," describes applications and lists the types available.

Monel—International Nickel Co., Inc., 67 Wall St., New York, N. Y. 8-page bulletin, "Engineering Properties of Monel Metal," including tables of physical constants, mechanical properties and a discussion of corrosion-resistant and working properties.

Stainless Steel—Subsidiary Manufacturing Companies of the United States Steel Corp. Well-illustrated, 36-page booklet, "Stainless and Heat-Resisting Alloy Steels," giving composition, physical properties, corrosion-resistance, working characteristics and metallurgy of chromium and chromium nickel alloy steels.

Welded Tubing—Steel & Tubes, Inc., Cleveland, Ohio. 68-page booklet, "Handbook of Electric Weld Tubing," including manufacture, weld characteristics, material, physical properties, types; complete catalog information on standard and special welded steel tubing.

Welding—Metal & Thermit Corp., 120 Broadway, New York, N. Y. Circular "Murex Straight Gap Welding," describing a new method of welding heavy plates.

Welding—Republic Steel Co., Massillon, Ohio. 18-page booklet, "Welding of Enduro Stainless Alloys," comprehensive data on types of alloys, various welding methods.

Wrought Iron—A. M. Byers Co., Pittsburgh, Pa. Well-prepared. 16-page booklet, "The Story of Ancient Wrought Iron," including a detailed but non-technical description of modern manufacturing methods.

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"Hoover Dam"

The Babcock & Wilcox Co., 85 Liberty St., New York, N. Y., have prepared Bulletin S-4 describing the Boulder Dam and reservoir, the diversion tunnels, power plant, and the design and testing of the various pipes, some of them 30 ft. in diameter. The booklet includes several diagrams, and many interesting photographs. The engineering features of the project are set forth in a manner that will appeal to all technical men. Particular attention is given to the problems involved in the construction of the steel pipe used in the diversion tunnels, as worked out by the Babcock & Wilcox Co.

Horsepower Capacities of Straight Bevel Gears—I

(PER INCH OF FACE WIDTH)

The tables given herewith give the horsepower ratings for straight bevel gears per inch of active face when the number of teeth, diametral pitch, and r.p.m. are known. These tables are similar to those on spur gearing published in the January and February, 1933, numbers of *Product Engineering* (pp. 39, 40, 79 and 80). They are based on the Lewis formula with the usual velocity factor as given by the Barth equation. In addition, the tables include a factor which limits the length of face to one-third of the pitch cone radius, which is the maximum face employed in the best gear practice. Pitch line velocities are also included in these tables to serve as a guide to the designer.

All information given in the previous article "Horsepower Capacities of Spur Gears," regarding allowable pitch line velocities, lubrication recommendations, and multiplying factors for other than 14½ deg. pressure angles, apply also to these tables for straight bevel gears.

The horsepower ratings in these tables are based on the use of high-grade cast iron as a gear material, allowable static stress being taken as 8,000 lb. per sq-in. based on elastic limit as was used for the tables on spur gears and the same material recommendations as well as the same material multiplying factors should be employed as recommended therein.

The ratings as given are per inch of face, provided the length of face is made equal to one-third of the pitch cone radius. For any given application, the ratings must be multiplied by the net contacting face of the gear in inches to arrive at the total allowable horsepower.

Effective length of face of a set of bevel gears is dependent upon their pitch diameters and the speed ratios. Unless this is taken into consideration, a longer face may be selected than is permissible, the tooth thickness at the end toward the apex of the cone becoming too thin. The accompanying table facilitates the calculation of the face length of either the gear or pinion tooth.

Face Length of Bevel Gear Teeth

Maximum length of face of tooth (1/3 slant height of pitch cone) is *A* times pitch diameter of pinion, or *B* times pitch diameter of gear.

Gear Ratio	Multiplying Factor *A*	*B*
1.00	0.236	0.236
1.25	0.267	0.213
1.50	0.300	0.200
1.75	0.336	0.192
2.00	0.373	0.186
2.50	0.449	0.179
3.00	0.527	0.176
4.00	0.687	0.172
5.00	0.850	0.170
6.00	1.013	0.169
8.00	1.342	0.168

1—Diametral Pitch

R.P.M.		Number of Teeth							
		12	14	16	20	25	30	50	100
750	V.	2360	....	....	....	....	....	....	....
	H.P.	16.6	....	....	....	....	....	....	....
600	V.	1880	2200	....	....	....	....	....	....
	H.P.	15.8	17.9	....	....	....	....	....	....
450	V.	1415	1650	1880	2360	....	....	....	....
	H.P.	13.7	16.7	18.9	21.9	....	....	....	....
300	V.	945	1100	1260	1570	1965	2360	....	....
	H.P.	12.7	14.8	16.9	19.9	22.6	24.6	....	....
200	V.	630	735	840	1050	1310	1570	....	....
	H.P.	10.7	12.5	14.6	17.5	20.3	22.3	....	....
150	V.	470	550	630	785	980	1180	1965	....
	H.P.	9.1	10.9	12.8	15.5	18.3	20.5	25.7	....
100	V.	315	370	420	525	655	785	1310	....
	H.P.	7.2	8.7	10.3	12.8	15.4	17.5	23.0	....
50	V.	155	185	210	260	325	390	655	1310
	H.P.	4.3	5.4	6.5	8.1	10.4	12.1	17.5	24.5
10	V.	31.5	37.0	42.0	53	66	79	131	260
	H.P.	.93	1.19	1.52	2.07	2.80	3.45	6.0	10.8
1	V.	3.1	3.7	4.2	5.3	6.6	7.9	13.1	26.2
	H.P.	.093	.119	.152	.207	.280	.345	.60	1.35

1¼—Diametral Pitch

R.P.M.		Number of Teeth							
		12	14	16	20	25	30	50	100
750	V.	1885	2200	....	....	....	....	....	....
	H.P.	12.6	14.4	....	....	....	....	....	....
600	V.	1510	1760	2010	....	....	....	....	....
	H.P.	11.9	13.7	15.4	....	....	....	....	....
450	V.	1130	1320	1510	1885	2360	....	....	....
	H.P.	10.9	12.5	14.4	16.6	18.9	....	....	....
300	V.	755	880	1005	1255	1570	1885	....	....
	H.P.	9.3	10.9	12.5	14.8	17.2	18.8	....	....
200	V.	505	585	670	840	1050	1260	2100	....
	H.P.	7.6	9.0	10.5	12.8	15.1	16.7	20.8	....
150	V.	380	440	505	630	785	945	1570	....
	H.P.	6.5	7.7	9.1	11.2	13.4	15.1	19.4	....
100	V.	250	295	335	420	525	630	1050	2100
	H.P.	4.9	6.0	7.1	9.0	11.1	12.6	17.1	22.2
50	V.	126	147	168	210	260	315	525	1050
	H.P.	2.87	3.60	4.3	5.7	7.1	8.5	12.5	18.2
10	V.	25.2	29.3	33.5	42.0	52	63	105	210
	H.P.	.61	.77	.95	1.31	1.76	2.20	4.0	7.4
1	V.	2.5	2.9	3.4	4.2	5.2	6.3	10.5	21.0
	H.P.	.061	.077	.095	.131	.176	.220	.40	.85

PRODUCT ENGINEERING © REFERENCE BOOK SHEET

Horsepower Capacities of Straight Bevel Gears—I

(PER INCH OF FACE WIDTH)

1½—Diametral Pitch

R.P.M.		Number of Teeth							
		12	14	16	20	25	30	50	100
900	V.	1890	2200	....	....	....	....	....	....
	H.P.	10.5	11.9	....	....	....	....	....	....
750	V.	1570	1835	2100	....	....	....	....	....
	H.P.	10.1	11.5	13.0	....	....	....	....	....
600	V.	1260	1470	1680	2100	....	....	....	....
	H.P.	9.4	10.8	12.3	14.2	....	....	....	....
450	V.	945	1100	1260	1570	1960	2360	....	....
	H.P.	8.5	9.9	11.3	13.2	15.1	16.4	....	....
300	V.	630	735	840	1050	1310	1570	....	....
	H.P.	7.1	8.4	9.7	11.6	13.5	14.9	....	....
200	V.	420	490	560	700	875	1050	1750	....
	H.P.	5.7	6.9	8.1	9.9	11.7	13.1	16.7	....
150	V.	315	365	420	525	655	785	1310	....
	H.P.	4.8	5.8	6.9	8.5	10.3	11.7	15.3	....
100	V.	210	245	280	350	435	525	875	1750
	H.P.	3.6	4.4	5.3	6.7	8.3	9.6	13.3	17.7
50	V.	105	122	140	175	220	260	435	875
	H.P.	2.06	2.57	3.15	4.1	5.3	6.2	9.4	14.1
10	V.	21.0	24.4	27.9	35.0	43.5	52	87	175
	H.P.	.43	.54	.67	.91	1.23	1.52	2.80	5.4
1	V.	2.1	2.4	2.8	3.5	4.4	5.2	8.7	17.5
	H.P.	.043	.054	.067	.091	.123	.152	.280	.59

2—Diametral Pitch

R.P.M.		Number of Teeth							
		12	14	16	20	25	30	50	100
1200	V.	1890	2200	....	....	....	....	....	....
	H.P.	7.9	9.0	....	....	....	....	....	....
900	V.	1415	1650	1890	2360	....	....	....	....
	H.P.	7.3	8.4	9.5	10.9	....	....	....	....
750	V.	1180	1380	1575	1965	....	....	....	....
	H.P.	6.9	8.0	9.1	10.5	....	....	....	....
600	V.	945	1100	1260	1575	1965	2360	....	....
	H.P.	6.4	7.4	8.5	9.9	11.3	12.3	....	....
450	V.	710	825	945	1180	1480	1770	....	....
	H.P.	5.7	6.6	7.7	9.1	10.5	11.5	....	....
300	V.	470	550	630	785	895	1180	1965	....
	H.P.	4.6	5.5	6.4	7.7	9.2	10.2	12.8	....
200	V.	315	365	420	525	655	785	1310	....
	H.P.	3.60	4.3	5.1	6.4	7.7	8.7	11.5	....
150	V.	235	275	315	395	490	590	985	1965
	H.P.	2.93	3.60	4.3	5.4	6.7	7.6	10.4	13.6
100	V.	157	183	210	260	330	390	655	1310
	H.P.	2.10	2.67	3.25	4.1	5.3	6.1	8.7	12.2
50	V.	79	92	105	131	164	196	330	655
	H.P.	1.18	1.51	1.87	2.46	3.20	3.80	5.9	9.3
10	V.	15.7	18.3	21.0	26.2	33.0	39.0	66	131
	H.P.	.237	.300	.375	.51	.69	.86	1.57	3.20
1	V.	1.57	1.83	2.1	2.6	3.3	3.9	6.6	13.1
	H.P.	.024	.030	.037	.051	.069	.086	.157	.320

2½—Diametral Pitch

R.P.M.		Number of Teeth							
		12	14	16	20	25	30	50	100
1200	V.	1510	1760	2010	....	....	....	....	....
	H.P.	5.9	6.8	7.7	....	....	....	....	....
900	V.	1130	1320	1510	1890	2360	....	....	....
	H.P.	5.5	6.3	7.1	8.3	9.4	....	....	....
750	V.	945	1100	1260	1575	1965	2360	....	....
	H.P.	5.1	5.9	6.7	7.9	9.1	9.8	....	....
600	V.	755	880	1010	1260	1575	1890	....	....
	H.P.	4.7	5.5	6.3	7.4	8.5	9.3	....	....
450	V.	565	660	755	945	1180	1415	2360	....
	H.P.	4.1	4.8	5.6	6.7	7.8	8.7	10.7	....
300	V.	380	440	505	630	785	945	1570	....
	H.P.	3.25	3.85	4.6	5.6	6.7	7.5	9.7	....
200	V.	250	295	335	420	525	630	1050	2100
	H.P.	2.46	3.00	3.60	4.5	5.5	6.3	8.5	10.9
150	V.	189	220	250	315	395	470	785	1570
	H.P.	2.00	2.46	2.94	3.80	4.7	5.4	7.6	10.1
100	V.	126	147	168	210	260	315	525	1050
	H.P.	1.44	1.80	2.20	2.80	3.60	4.3	6.3	8.9
50	V.	63	73	84	105	131	157	260	525
	H.P.	.75	.95	1.20	1.64	2.14	2.54	4.1	6.7
10	V.	12.6	14.7	16.8	21.0	26.2	31.5	53	105
	H.P.	.150	.191	.240	.325	.45	.55	1.01	2.14
1	V.	1.26	1.47	1.68	2.1	2.6	3.1	5.3	10.5
	H.P.	.015	.019	.024	.033	.045	.055	.101	.215

3—Diametral Pitch

R.P.M.		Number of Teeth							
		12	14	16	20	25	30	50	100
1800	V.	1890	2200	....	....	....	....	....	....
	H.P.	5.3	6.0	....	....	....	....	....	....
1200	V.	1260	1470	1680	2100	....	....	....	....
	H.P.	4.7	5.4	6.1	7.1	....	....	....	....
900	V.	945	1100	1260	1570	1965	2360	....	....
	H.P.	4.3	4.9	5.7	6.6	7.5	8.2	....	....
750	V.	785	920	1050	1310	1640	1965	....	....
	H.P.	3.95	4.6	5.3	6.3	7.2	7.9	....	....
600	V.	630	735	840	1050	1310	1570	....	....
	H.P.	3.55	4.2	4.9	5.8	6.8	7.4	....	....
450	V.	470	550	630	785	985	1180	1965	....
	H.P.	3.05	3.65	4.3	5.1	6.1	6.8	8.6	....
300	V.	315	365	420	525	655	785	1310	....
	H.P.	2.40	2.87	3.45	4.3	5.1	5.8	7.7	....
200	V.	210	245	280	350	435	525	875	1750
	H.P.	1.80	2.20	2.67	3.35	4.1	4.8	6.6	8.9
150	V.	157	183	210	260	330	395	655	1310
	H.P.	1.44	1.79	2.14	2.74	3.45	4.1	5.9	8.1
100	V.	105	122	140	175	220	260	435	875
	H.P.	1.04	1.29	1.57	2.07	2.63	3.15	4.7	7.1
50	V.	52	61	70	87	109	131	220	435
	H.P.	.52	.67	.83	1.13	1.52	1.84	3.00	5.0
10	V.	10.5	12.2	14.0	17.5	21.8	26.2	43.5	87
	H.P.	.104	.133	.167	.226	.305	.390	.69	1.48
1	V.	1.05	1.22	1.40	1.75	2.2	2.6	4.4	8.7
	H.P.	.010	.013	.017	.023	.031	.039	.069	.148

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